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<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> The Final Proceedings for Intelligent decisions? Intelligent support?, 29 August 2005 - 2 September 2005 The meeting is not organized as a conventional meeting with paper presentation in sessions, but rather as a structured discussion on a central theme. A number of themes will be addressed. The idea has therefore emerged to reconvene the participants from the meeting in San Miniato in 1985, to take a second look at intelligent decision support systems (IDSS), and to discuss what has actually happened in the twenty years that have passed. The motivation is that IDSS still is an important research and application area, but that we also now know where the ambitions were too high. More concretely, the purpose is both to assess what has happened in the field in the twenty years that have gone, and to develop a perspective on what needs to be done in the future. Since many of the 1985 participants have been actively engaged in the field, they are certainly in a unique position to do this. The first 2,5 days will be reserved for the participants of the 1985 AS, to compare the view on IDSS of 1985 with the present (2005) view. The following 2,5 days will welcome 'new' participants, to provide a more extensive discussion of the state-of-the-art, of needs and requirements to IDSS now and the near term, and of ongoing developments.					
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# **Intelligent Decisions? Intelligent Support?**

**Agenda and Participants for the  
International Workshop on  
Intelligent Decision Support Systems:  
Retrospects and Prospects  
August 29 - September 2, 2005  
Certosa di Pontignano (Siena), Italy**

**To mark the 20th anniversary of the NATO ASI on  
Intelligent Decision Support in Process Environments  
September 16-27, 1985  
San Miniato (Italy)**

**Organising Committee**

**Pietro Carlo Cacciabue, Joint Research Centre Ispra, Italy**

**Erik Hollnagel, University of Linköping, Sweden**

**Antonio Rizzo, University of Siena, Italy**

**Penelope Sanderson, University of Queensland, Australia**

**John Wilson, Nottingham University, UK**

**David D. Woods, Ohio State University, USA**

**Sponsored by**

**University of Siena**

**Ohio State University**

**European Office of Aerospace Research and Development**

## FINAL AGENDA: REUNION

August 29	Reunion – Day 1
09:00 – 10:30	Welcome Introduction – oldies and freshmen Theme R1: The landscape in 1985 - real needs and perceived solutions.
10:30 – 11:00	Coffee break
11:00 – 12:30	Theme R2: Relevant scientific disciplines in 1985 vs. 2005 - the changing reality The 1985 proceedings conclude by listing the following four themes: Decision Theory, Systems Engineering, Cognitive Engineering, and Artificial Intelligence. One obvious question is whether the four themes still are relevant for IDSS research.
12:30 – 14:30	Lunch
14:30 – 16:00	Theme R3: Changes in the 'research landscape' / changes in the 'industrial landscape' – converging perspectives
16:00 – 16:30	Coffee break
16:30 -18:00	Breakout sessions. The 1985 participants are required to extract from the Proceedings from 1985 the main themes, theoretical and practical advances, methods and predictions etc, and in a structured fashion subject them each to 5-10 minutes of discussion and retrospective critique, spread amongst several small teams in a set of breakout sessions.

August 30	Reunion – Day 2
09:00 – 10:30	Theme R4: Spectacular successes of intelligent decision support, including expert systems – and spectacular failures
10:30 – 11:00	Coffee break
11:00 – 12:30	Theme R5: Problems that remained unsolved
12:30 – 14:30	Lunch
14:30 – 16:00	Theme R6: What have we learned, what have we yet to learn?
16:00 – 16:30	Coffee break
16:30 -18:00	Preparation of hand-over to workshop Conclusions

## FINAL AGENDA: WORKSHOP

August 31	Workshop – Day 1
09:00 – 10:30	Introduction Presentation of participants
10:30 – 11:00	Coffee break
11:00 – 12:30	Hand-over from reunion
12:30 – 14:30	Lunch
14:30 – 16:00	Theme W1: Decision making and knowledge
16:00 – 16:30	Coffee break
16:30 -18:00	Theme W2: Decision making, communication and control

September 01	Workshop – Day 2
09:00 – 10:30	Theme W3: Complexity
10:30 – 11:00	Coffee break
11:00 – 12:30	Theme W4: Philosophy of IDSS
12:30 – 14:30	Lunch
14:30 – 16:00	Theme W5: Social systems – technology in a context
16:00 – 16:30	Coffee break
16:30 -18:00	Theme W6: Autonomous systems and Industrial automation

September 02	Workshop – Day 3
09:00 – 10:30	Theme W7: Models and methods, especially role of mental/cognitive models
10:30 – 11:00	Coffee break
11:00 – 12:30	Theme W8: Intelligent people or intelligent machines?
12:30 – 14:30	Lunch
14:30 – 16:00	Theme W9: The way ahead
16:00 – 16:30	Coffee break
16:30 -18:00	Conclusions – documentation of workshop

## REUNION PARTICIPANTS

IDSS 'oldies'	Pietro Carlo Cacciabue
	Giovanni Guida (possibly by proxy)
	Erik Hollnagel
	Morten Lind
	Giuseppe Mancini
	Neville Moray
	Leena Norros
	Antonio Rizzo
	Penny Sanderson
	Erland Svensson
	John R. Wilson
IDSS 'freshmen'	David D. Woods
	Daniele Baranzini
	Elisa De Grandis
	Trudi Farrington-Darby
	Björn Johansson
	Luigi Macchi
	Anne Miller
	Simone Pozzi
	Lucca Save
	Sarah Sharples
	Fabio Tango
	Marcus Watson
	Rogier Woltjer

## WORKSHOP PARTICIPANTS

	Robert Bolia
	Kevin Corker
	Yushi Fujita
	Gudela Grote
	Robert Hoffman
	Toshiyuki Inagaki
	Sara Kraemer
	Michael May
	Nick McDonald
	Neelam Naikar
	Anne-Sophie Nyssen
	Johannes Petersen
	Amy Pritchett
	Axel Schulte
	Peter Svenmarck
	Robert Taylor
	John Wreathall
	Wan Chul Yoon

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## **1. BARANZINI, DANIELE; MACCHI, LUIGI; DE GRANDIS, ELISA; CACCIABUE, P. C.: CONCEPT OF DEVICE VERSUS ACTIVITY IN DECISION SUPPORT SYSTEMS**

The concept of intelligent decision support systems in several work domains (i.e., healthcare, process industry, aircraft maintenance, human spaceflight) has been frequently operationalised into formal devices. These are narrow but robust programs or software tools containing enhanced computational power, providing humans with solid heuristics/algorithms in order to reach higher and better decision solutions.

These systems are envisaged as either basic support tools or prostheses of human intelligence depending by the school of thought (Feltovich et al., 1997). Therefore, in this view the formal structure contains the guidance in the form of pieces of information and knowledge to varying degrees of freedom, by which human supervision is led or accompanied across families of solutions. These systems do support, in the sense that they broaden the band of valid and reliable alternatives to joint human-machine decisions.

The scenario depicted above is general and does not cover, or focus on any specific application. However, it follows from this that the concepts of decision and support conveyed a particular meaning into the role of a device embedding both concepts of decision and support.

Notably what is left out of the equation is the idea that decisions may be described as practices in context. Decisions are constantly shaped by events, situations or unexpected activities often not contained in the support system or device.

What we propose in this case is to extend the concept of support externally to the device assuming that the intelligence should be associated to the process or activity and not to the device itself.

The proposition statement will be discussed in the light of three different case studies encompassing flight operations, aircraft maintenance and automotive environments. A brief introduction of the three cases follows:

- Team systems in aircraft maintenance: planning and scheduling nightmares. At any point in time within an hangar, there are several maintenance check plans and schedules with different speeds and progressions. Multiple concurrent plans and schedules generate multiple paths of actions and decisions affecting dedicated operational teams. Reliable and flexible decisions support systems for man/power allocation, re-scheduling of operations, reconfiguration of trades and grades in the teams are limited in their predictive capacity and support on how to block key variances in the operations. New support systems appear to be rigid.
- Intelligent Speed Adaptation (ISA). ISA is a system by which the vehicle "knows" the permitted or recommended maximum speed for the road. The standard system uses an in-vehicle digital road map onto which speed limits have been coded, combined with a positioning system which could be GPS. This system, if not incorporated in an "intelligent" framework, is not able to take into consideration the general context, both the environmental and social one, in which the "driving" activities takes place.

- Traffic Alert & Collision Avoidance System (TCAS) and Überlingen Accident. TCAS scans the vicinity by interrogating the transponders of other aircraft. It then uses the received transponder signals to compute distance, bearing and altitude relative to the own aircraft. As TCAS checks the other aircraft's relative distance permanently in short time intervals, it can, therefore, also calculate the other aircraft's closure rate relative to the own aircraft. When TCAS detects that an aircraft's distance and closure rate becomes critical, TCAS generates aural and visual annunciations for the pilots. If necessary, it also computes aural and visual pitch commands to resolve a conflict. The in-flight collision happened in the skies of Überlingen (Germany) in July 2002 showed that integration of TCAS into the system aviation was insufficient and did not correspond in all points with the system philosophy.

#### Reference

Feltovich, P. J., Ford K. M. & Hoffman, R. R. (1997). Expertise in context: Human and machine. MIT Press.

## **2. BOLIA, ROBERT: INTELLIGENT DECISION SUPPORT SYSTEMS IN NETWORK-CENTRIC MILITARY OPERATIONS**

The investment by the United States Air Force in intelligent decision support systems (DSS) is being driven increasingly by the requirements of Network-Centric Warfare (NCW; Cebrowski & Garstka, 1998; Alberts, Garstka, & Stein, 1999; Alberts & Hayes, 2003). NCW is a concept of operations which claims that the dense networking of sensors and shooters will provide commanders with an unprecedented level of situation awareness (SA), that this SA will be shared via a common operational picture (COP), and that the shared SA so cultivated will increase the effective speed of command and enable self-synchronization of forces. The prophets of this dogma allege that it offers no less than a revolution in military affairs. Indeed, they have proposed that the NCW thesis – specifically, the magnitude and ubiquity of information guaranteed by the COP – implies a transformation of the traditional hierarchical chain of command such that decisions previously made at the top of the pyramid will be pushed down to lower levels, a concept known as power to the edge (Alberts & Hayes, 2003).

Needless to say, there have been challenges to this position almost from its inception (Barnett, 1999), which have not yet abated (Kaufman, 2005). NCW has been attacked for its shaky foundations (Griffin & Reid, 2003; Bolia, Nelson, & Vidulich, in press), its dubious logic (Barnett, 1999), its inadmission of countermeasures (Bolia, 2004), and its technological fragility (Talbot, 2004), in addition to the fact that it appears to be driven by the commercial availability of technology rather than operationally derived military requirements (Kaufman, 2005). To researchers in the Air Force Research Laboratory's Human Effectiveness Directorate, however, the most interesting questions with respect to NCW revolve around the possible unintended consequences for the human operator, all of which have bearing on human interaction with intelligent DSSs (Bolia, Vidulich, & Nelson, 2005).

Perhaps the most immediately obvious issue is that of information, for NCW will ostensibly provide operators at all levels of the command chain with an amount of information unparalleled in the history of warfare. Yet this is only an advantage under the assumption that more information is always better, when in fact there are innumerable cases in which this assumption does not hold. There are, for example, issues of data quality, data relevance, and data interpretation, as well as the illusion of completeness – the idea that one doesn't know what one doesn't know (Bolia, Vidulich, Nelson, & Cook, 2003). But even if the data are verifiably good data, information overload may still be an issue. The idea that a system can handle more information because of an increase in network capacity or bandwidth does not mean that the operator using the system can do the same. It is here that the requirement for decision support is levied upon the system.

But there are problems with intelligent decision support for military commanders, not the least of which is the fundamental complexity and uncertainty of war itself (Clausewitz, 2002). Classic DSSs – rule-based or knowledge-based systems – employ a flowchart or filter model, in which a decision or course of action is determined by the set of truths satisfied by the data (Russell & Norvig, 1995). The benefit of these systems is that they are closed, and as such the context of the problem is encoded implicitly in the data provided. Unfortunately, they work well only for problems that are either relatively small in scope, such as troubleshooting a piece of hardware, or

relatively well-understood and well-described by subject-matter experts, such as medical diagnosis. In larger or more complex domains, analogous systems may be constructed using nonlinear pattern recognition techniques such as neural networks.

There are at least two problems with the use of such systems in the realm of combat. First, there is the problem of representation. This is engendered in part by the complexity of the problem, in part by its multidimensionality, and in part by the failure of scientists to make more than a minor dent in the twin problems of context encoding and semantic comprehension (Bolia, Nelson, Vidulich, & Taylor, 2004). It is easy enough to encode the positions of friendly and enemy units, along with information about their combat effectiveness, the terrain in which they are located, and even the weather. But is this enough context? What about activity on other fronts that may affect the battle? What about dynamic rules of engagement? It is not immediately clear how these critical factors integrate with the varieties of information commonly encoded in a spatio-temporal grid. Moreover, the DSS will not have the long-term context that an individual commander might build up over the course of a campaign. Finally, even if the problem of context representation is solved, the problem of interpretation of the context remains.

The idea that the COP will not eliminate hermeneutical discrepancies has been raised before (Bolia, Vidulich, & Nelson, 2005), and is tied to the second problem: the difficulty of predicting adversarial decisions. In nearly every battle, the success or failure of a commander's action depends heavily on the action of the enemy commander. This poses several problems: 1) how to represent the adversary's perception and comprehension of the situation; 2) how to represent the adversary's strategic vision; and 3) how these might interact to form the interpretation that will lead to a decision.

It might be insinuated that doctrine is the answer, and so superficially would it appear to be. But doctrine leaves plenty of room for contradiction. For example, conventional military doctrine suggests that a commander not divide his forces in the face of an enemy. Yet the same doctrine also points to surprise as one of the fundamental principles of war (Sun Tzu, 1963). What happens when a commander divides his force simply because he knows that the enemy, relying on the doctrine commonly accepted by both sides, believes that he would never do so (Bolia, Nelson, Vidulich, & Taylor, 2004)? Now he has the element of surprise, which, depending on the context, may be more important than mass.

This begins to hint at another question, which is more epistemological in nature. If a DSS is to provide information, how is it to know what is the right information; if it is to provide a course of action, in other words offer a decision, how is it to know what is the right decision. More generally, given a desired outcome, does a correct decision exist? More generally still, given a collection of decisions, is it possible under every circumstance to assign values to these decisions such that they can be ordered according to decision quality? Is it possible to do this in any except the most trivial circumstances?

It is here that the importance of the adversary's decision becomes clear. It is easy to conceive of a situation in a two-person game in which a player arrives at the brink of victory only to be parried by a decisive move by his opponent. It should also be apparent to any student of military history that battles are at least as often lost as won; that is to say, it may be easier to identify the losing move of the vanquished than the

winning move of the victor (Bolia, 2005). This is a problem in real-time, of course, for reasons already identified. But as Simon (1974) has pointed out, even in games of perfect information, in which the only variable is the adversary's decision, it is often impossible to resolve, even *ex post facto*, which was the losing move. Somewhat incongruously, this has been less of an issue in military history, although why a particular "losing move" was selected has been the topic of much speculation. For example, 142 years after the fact, the debate rages on about why Lee chose to attack the Union center on the third day of the Battle of Gettysburg, despite the fact that a frontal assault against prepared defenses not only went against prevailing doctrine but against Lee's experience as the defending commander at Fredericksburg.

Of course, the idea may be introduced that commanders in battle do not make rational decisions in the sense of enumerating courses of action and choosing the best among them, but rather make recognition-primed decisions according to the model of expert decision making put forth by Klein (1997, 1998), in which decision quality is secondary to decision speed. But this is not helpful in the construction of real-time DSSs, since in Klein's model the recognition triggers not only apprehension but also comprehension of the situation, which the DSS does not have. Moreover, it has been pointed out that recognition-primed decisions may in fact be compromised by the introduction of intelligent decision support, since the interaction with the DSS may require more time than it might have taken the commander to make a recognition primed decision (Bolia, Nelson, Vidulich, & Taylor, 2004).

In addition to the problems associated with measurement of decision quality, the commander's interaction with the DSS must be considered. Parasuraman and his colleagues, among others, have pointed out a number of unintended consequences of human interaction with highly automated systems (Parasuraman & Riley, 1999). For example, if a commander does not have confidence in the DSS, he may spend an inordinate amount of time "drilling down" to inspect the sources of the information provided, rendering it useless in a time-sensitive environment, or he may elect not to use it at all. On the other hand, overconfidence in the DSS – an example of a phenomenon associated with highly reliable automated systems that has been termed "automation complacency" – may lead to a commander's acceptance of a course of action even though it is inappropriate. Also, increasing reliance by commanders on the DSS may engender degradation in their unaided decision making skills, which will still be needed if connections to the network are lost or in case of electrical power failure.

Finally, there are ethical issues linked to the use of automated decision support. The individual commander is ultimately responsible for the decisions he makes, but will he be held accountable by a court martial if he was following the flawed advice of an otherwise reliable DSS? One of the tenets of NCW is that increased information availability and intelligent decision support will allow decisions formerly made by lieutenant colonels to be made by lieutenants. What the former presumably have that the latter almost certainly lack is an expertise based on experience that may help them to better evaluate the course of action proposed by the DSS and avoid some of the aforementioned automation failures.

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### **3. CORKER, KEVIN: EXPERIENCE & REQUIREMENT: COGNITIVE ORIENTATION IN DEVELOPMENT OF DECISION SUPPORT TOOLS ADVANCED AEROSPACE OPERATIONS**

Decisions with respect the operation of international air transportation services are taken on scales from seconds to months, impacting behavior from meters to miles and are made by automation, individual human operators, corporations, and regulatory government agencies. All of these decisions interact in the real time theatre of operations, and all are supported by one, or many, decision support systems. In the design, definition, deployment, adaptation and adoption of these systems, patterns of behavior for human-system integration are observed. The patterns either amplify or diminish the impact of the decision aiding and the consequent overall joint cognitive system effectiveness. The goal of this discussion is to sketch the consistent outline of these patterns from experience in the aerospace domain in order to provide predictive support, not only for the final adapted use of the systems, but also to plot the transition trajectory of inserting decision support tools at various levels and in varied epochs of the aviation systems evolution.

#### **3.1 Decision Aiding Dimensions:**

Decision support is provided in all cases in which it is assumed that either by the pace, scale or the complexity of operations the human cannot make “optimal, accurate or timely responses”. As it was expressed a recent international symposium on aviation (USA/Europe ATM Symposium, 2005), “when there is a difference between available and achieved performance, then decision support tools are brought to bear.” These gaps between optimal and actual are expressed with respect to:

- Safety: The difference between no accident/incidents in system and the loss of life, property and operating margin that is observed
- Efficiency: The gap between demand at a time and capacity at that time to accommodate all users
- Adaptability: The tension between prediction and flexible response at every level of operation from flight deck response to airspace configuration.
- Schedule: The mismatch between what the advertised operations and the actual operation provide in route and time of service
- Reliability: The difference between just-in-time maintenance and system degraded operation
- Cost: The shrinking margin between revenue and costs in passenger-seat miles.

In all cases in which there is a perceived gap, decision support of various configuration is deployed. There is a universal assessment that “decisions” need to be aided. However, there is a much less clear consensus about what constitutes a decision and who has the responsibility for its “making”. And there is reluctance, in this provision of public service, to remove the human practitioner from final responsibility for performance. There is, therefore, an assumption that some human practitioner (at some level in the action cycle) will identify failure (i.e. determine that the parameters of operation have

been exceeded), correct, or adjust the decision aiding system under anomalous operations.

### **3.2 Determinants of Decision Aiding Adoption:**

The aforementioned assumption of human responsibility (and consequent dilemma of intervention and reversion) in the joint cognitive system is one driver in the trajectories of adaptation observed with decision aiding systems. There are at least two others of primary significance in adoption.

The decision-making processes in this system are widely distributed in space and time. The human operators (designers, pilots, air traffic controllers, and airline operations personnel, corporate entities and governments) must monitor and predict any change in the distribution of authority or control that might result as a function of the airspace configuration, aircraft state or equipment, and other operational constraints. The operators are making decisions and sharing information not only about the management of the airspace, but also about the operating state of that airspace, and about the operating behaviors of the automation that is in place to aid them. In so doing, they are moving from direct participatory to supervisory roles and from supervisory roles to automated system monitoring and control by exception.

The notion of anomaly (what constitutes an exception) in the interrelated but independent spheres of operation is fundamentally ambiguous. What is an anomaly in a system of distributed discretion, where pilot action (though perhaps different from a controller's intention or preference) is allowed under relaxed self-separation operations? Or to take another view, what is an actionable alert where layers of automated information system provide (to all participants) levels of alert and warning for potential future anomalies, or conflicts that are subject to change through any of several agents' actions?

### **3.3 Trajectories of Decision Aiding Adoption:**

These are arenas where knowledge about cognitive bottlenecks, human-system interaction, and system dynamics and stability is critical. Based on experiment, modeling, observation and design, we suggest that there are several commonly identifiable patterns of concern arising from decision aiding:

- Shared Values becomes a dominant issue in the development of aiding systems. Operation must converge on similar valuation processes, and these processes must be kept consistent as the field of operation changes. This requirement holds from conflict alert to schedule determination.
- Switching mechanisms among tasks at hand and tasks of advisory assessment become critical design elements.
- Team composition impacts of decision aiding are potentially destabilizing.
- Individual tailoring of decision advisory is little understood in its impact on effectiveness and on team operation

- Maintenance of paths of least constraint for human operation under decision aiding demands for immediate optimization are leading operators to “get out ahead” of the aiding system thereby defeating its intended benefits.
- Risk equivalence operations are being observed as controllers and pilots test the limits of their joint operation with decision aiding
- Methods of information integration and segregation are being observed as the decision aid’s integration or segregation is found inadequate to other tasks of information management not anticipated by designers.

Finally, I would like to suggest that, as a socio-technical problem, several critical influences can be identified that determine the rate of deployment and adaptation to decision aiding:

1. Safety Critical Decision Aiding systems have been influenced in their deployment by grants of “limited immunity” to operators who will agree to their use.
2. Economically Critical Decision Aiding systems have been accelerated in their deployment through “incentives” to users who agree to use the “optimal” information provided.
3. Sociotechnical Incentives in Decision Aiding systems are being implemented in response to workforce changes and synchronized mandatory retirement of the air traffic and pilot workforce.
4. Technico-Organization Incentives are being brought to bear on Decision Aiding system deployment as infrastructure support for current operations are decommissioned and organizations are reconfigured to match new command and control capabilities.

The impact of these drivers and their interaction with the issues of adaptation could be used to support prediction of both the success and potential for failure of current practice in decision aiding.

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#### **4. FARRINGTON-DARBY, TRUDI (WITH WILSON, JOHN): EXPERTISE AS A SOCIALLY BASED CONSTRUCT**

Knowledge acquisition is often seen as the cornerstone of the development of expert systems. These systems promise to act instead of, or support the overloaded, unreliable and limited human being using what is considered to be the most efficient and optimal performance. This we know has not been the case with many reasons suggested for the shortcomings of this claim.

UK railway network controllers are a group of operators who control a mechanically and electronically operating system through other people. This paper uses railway controllers' work as a case of humans working in a sociotechnical system from which to explore a notion of expertise as a social construct. Whereas there has been much interest in technical skills and knowledge to perform work the social skills and knowledge of the social system has perhaps been given less attention.

Through the study of railway controllers we were able to identify key steps of their work and where the challenges arise. These challenges were partly cognitive but were also related to the controller's knowledge of the people with which they worked. Several themes underlying the concept of "social expertise" were identified such as social skills, knowledge of social systems, trust in information sources when they are human and non-technological, knowledge of information networks and how they can be accessed.

As part of this longer naturalistic study of the work of controllers, findings investigating the nature of expertise within their work has prompted a specific look at the implications for firstly, the methods that attempt to capture and represent expertise if the concept of "social expertise" is acknowledged as part of expertise, and secondly how we go about the support and development of "social expertise" through system development, training and job design.

## **5. FUJITA, YUSHI: EMPATHETIC ROBOTS: A METHOD FOR ENHANCING HUMAN ABILITIES?**

A girl is staring into an animal robot with affectionate eyes and utters with heartfelt voices “What a cute thing you are!” A toymaker made a runaway success, a baby doll which speaks in response to human voices “Take me for a walk.” It is said that there are over one thousand expressions the doll can make. This doll hit an all-time high to middle aged Japanese folks, especially those who are in their fifties. An English teaching tool called “Wizzy” talks back in response to questions given by learners. It says “Try again” otherwise the learner gives a correct pronunciation. It is getting popularity among Japanese English learners because they say they do not feel embarrassed, which they often times do with “real” human teachers. These examples, among many others, suggest that empathetic feelings emerge between humans and robots of some types, and that this empathy for artifacts is broadening human minds and even enhancing human abilities. Perhaps the artifacts are a mirror of humans who face them, and the humans can see themselves, through interactions with the artifacts, more objectively. Given that maximizing human abilities is the role of intelligent decision support systems, the empathetic approach mentioned above may be worthwhile discussing. In addition, this line of discussion will lead us to discuss a concern that these robots, regardless of physical appearances they possess, may actually shape our mentality.

## **6. GROTE, GUDELA: HUMAN CONTROL OF TECHNICAL SYSTEMS - A MISLEADING PRESUMPTION**

### **Abstract**

Regardless of a system's degree of automation, it is humans who are responsible for its functioning. The requirement of human controllability of technical systems is derived from this responsibility. Human factors based methods for the design of human-machine systems are meant to support engineers in designing systems that are controllable by the human operator under all conditions. KOMPASS is introduced as an example of these methods. In view of human fallibility in combination with loss of control over technical systems as ascertained in many incident and accident analyses, it can be questioned how achievable the goal of human control over technology really is. Reasons for lack of controllability can be found in the normative assumptions of those developing and implementing technology, as the frequently expressed view of humans as risk factors to be excluded from processes via technology produces technical systems that do not conform to human capabilities. With the increasing complexity of technology, its controllability per se has to be questioned more and more. In this paper therefore, it is suggested to found system design on the premise of (partial) non-controllability of technology. The central purpose of this approach is to help human operators to better deal with system opaqueness and uncertainty by providing them with systematic information on the limits of control over the technical system and by also relieving them of some of their responsibility. System designers and the organizations using these systems as well as societal institutions have to take on responsibility for use of technical systems whose complexity can no longer be mastered entirely.

### **6.1 Humans assuming responsibility as basic requirement for the functioning of socio-technical systems**

Every automated system is a socio-technical system, independent of its degree of automation, as the workerless factory, the driverless subway or automated money transfer systems have been developed by humans for humans. Therefore, technical systems should never be looked at in isolation, but always as part of a socio-technical system, which includes the humans operating the system and the formal and informal structures and processes within which they work. In order to take all relationships relevant for the socio-technical system's functioning into account, it is also necessary to include in the system definition all those organizations and organizational units which are in charge of system design and maintenance as well as those that are responsible for rules and regulations controlling system design and operation. This very broad system definition is particularly useful when the distribution of responsibility has to be decided. As Timpe (2001) has pointed out, increasingly complex and distributed socio-technical systems further the diffusion of responsibility. Using driver systems as an example he argues that automation has to always leave people in control, so that they can assume responsibility.

Many authors agree (e.g. Boy, 1998; Grote, 1999; Hollnagel & Woods, 2005) that the limits of automation are not only determined by technological capabilities and social acceptance, but even more so by the necessity to keep humans in control so that they can be made responsible for achieving system goals and all associated positive and negative consequences. With increasing automation of even very complex decision processes and with so-called learning systems, these limits become more and more

blurred. In a very broad interdisciplinary project on the future of robotics, it was therefore argued that the learning goal, process and results in such technical systems have to be made transparent for the human user to allow him or her to influence and potentially even reverse the learning (Christaller et al., 2001). Again this points to the importance of influence on and control over technical systems.

Taking human responsibility as a premise, the prerequisites for controllability of technical systems are discussed in the next section. Subsequently, it is shown that these prerequisites are frequently unfulfilled and it is questioned to what extent they realistically can be implemented. In the final section, consequences for system design are presented.

## **6.2 Prerequisites for human control over technical systems**

The KOMPASS (Complementary analysis and design of production tasks in socio-technical systems) method (Grote et al., 2000; Wäfler et al., 2003) is presented as representative of many system design methods whose core tenet is human control over technology (e.g. Hollnagel, 2003; Timpe, Jürgensohn & Kolrep, 2002).

KOMPASS was developed to support an integral and prospective design of human-machine systems based on the principle of complementarity of human operator and technology. The complementary approach explicitly takes into account that humans and technology have specific strengths and weaknesses. Differing from the comparative approach (cf. Bailey, 1989), these strengths and weaknesses are not used for competing assignments of tasks to either human or technology, but for a consistent design of the human-technology interaction, thereby producing a joint system of a new quality. In the KOMPASS method, design criteria for the three levels of analysis of human-machine interaction, human tasks, and work system were defined with the overall objective of supporting the socio-technical system's capability of controlling variances at their source (see Fig. 1). The conceptual basis is the management of uncertainty as proposed by Grote (1997; 2004), which postulates that especially with a high level of uncertainties in transformation processes and/or the system's environment, the system has to be rendered capable of coping with uncertainties by strengthening the local actors' competence, instead of trying to minimize uncertainties by strict centralization.

At the level of human-machine interaction, KOMPASS operationalizes the requirement of human control over the technology in terms of the three elements of control, i.e. transparency, predictability, and means of influence. Four design criteria are defined: process transparency, dynamic coupling, information and execution authority, and flexibility. At the level of the human task, the main objective is to further intrinsic motivation through task orientation by means of design of humane tasks (e.g. Ulich, 1994). At the level of the work system, self-regulation in small control loops is aimed for in accordance with the socio-technical systems approach, encompassing design criteria such as task completeness and independence, polyvalence, group autonomy, and supervisor's boundary regulation (e.g. Susman, 1976; Pasmore, 1988).

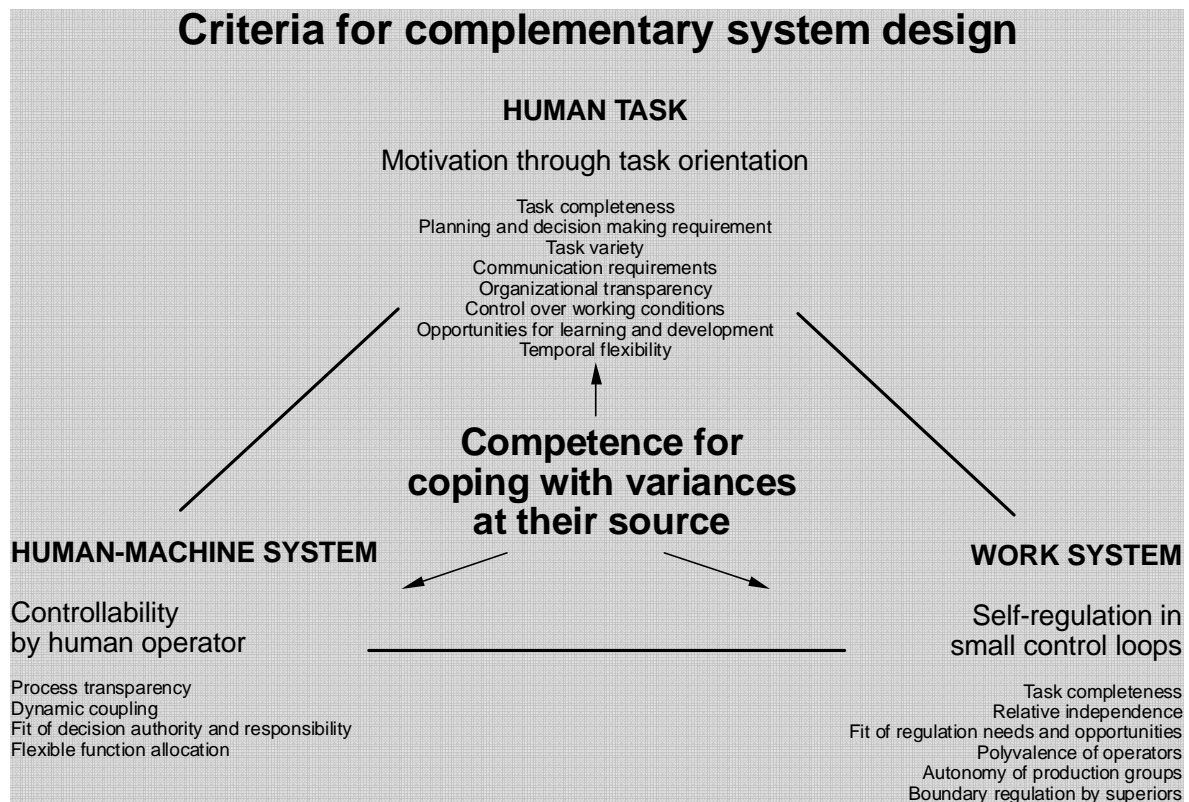


Figure 1. The KOMPASS design approach

Differing from other methods for task analysis and design, KOMPASS aims at supporting both the human operators' cognitive readiness to perform their role in the human-machine system as well as their motivation to use their cognitive capabilities in line with the system goals. An example of this is the requirement to match information and execution authority such that the human's actual influence over the technical process as defined by the distribution of execution authority makes him or her *want* to use the available information on the technical system as defined by the distribution of information authority. Often automatic systems provide the human operator with a lot of information without assigning him or her functions that would necessitate the use of this information. In incidents that involve lack of acknowledgement of available information, the human operator is often held responsible, thereby neglecting problems of potentially too much information (cf. the discussion of adequate alarm filtering, e.g. Papadopoulos & McDermid, 2001) and of too few incentives to continuously monitor all information available due to lack of action requirements for the human operator.

In a number of design projects, KOMPASS has proven useful especially for making explicit and for provoking controversial discussions of the fundamental issue of control and responsibility in socio-technical systems. Deriving specific consequences in terms of decisions on function allocation has often been difficult, though, due to the large number of partially interdependent criteria. In order to overcome these difficulties, a prototype of a computer-supported version of KOMPASS was developed and tested in a few cases (Davidsson et al., 2002; Jongkind et al., 2002). The results were encouraging, but to date the prototype has not yet been developed into a fully operational method. In doing so, great care would also have to be taken to not "automate" function allocation decisions in the very way that the method itself tries to avoid.

In addition to these more pragmatic difficulties with methods such as KOPMASS, the basic approach of demanding complete human control over technology may be wrong. This fundamental doubt is expanded on in the following sections.

### **6.3 Lack of human control over technical systems as core of "human unreliability"**

The main conclusion of incident and accident analyses across industrial sectors is that human error is an important or even the dominant causal factor. At the same time, there is more and more acceptance of the fact that accidents are always caused by a complex combination of human, technical, organizational, social and environmental factors, which may contain latent failures that only through erroneous human action "at the sharp end" will actually lead to accidents (e.g. Reason, 1997). Bainbridge's article on the ironies of automation is still the most impressive description of the unfortunate coupling of human and technology:

"(...) the automatic control system has been put in because it can do the job better than the operator, but yet the operator is being asked to monitor whether it is working effectively. (...) if the decisions can be fully specified then a computer can make them more quickly, taking into account more decisions and using more accurately specified criteria than a human operator can. There is therefore no way in which the human operator can check in real-time that the computer is following its rules correctly. One can therefore only expect the operator to monitor the computer's decisions at some meta-level, to decide whether the computer's decisions are 'acceptable'. If the computer is being used to make the decisions because human judgement and intuitive reasoning are not adequate in this context, then which of the decisions is to be accepted? The human monitor has been given an impossible task." (Bainbridge, 1982, pp. 130-131)

A frequently cited example of this problematic interaction between human and technology is the accident of a Lufthansa Airbus A320 in Warsaw, where the automatic algorithm - with no manual override - for braking the aircraft after touchdown on the runway was instigated too late resulting in the aircraft crashing into a earthen mound at the end of the runway. As a consequence of this accident, Lufthansa pilots were informed in more detail about the technical definition of the landing procedure and some technical improvements of the Lufthansa Airbus airplanes were implemented. The fully automatic - i.e. not allowing any human influence - release of reverse thrust and of the brakes during landing was left unchanged.

The problems resulting from taking away control from the human operator in this way have been described very well by Amalberti (1992, 1993). He assumes that human operators act on the basis of an "ecological risk management":

"In summary, pilots know they are resource limited. They thus develop sophisticated strategies to adapt to task demands. The problems to solve are twofold. The first is to switch between parallel activities directed to different temporal horizons with the safest strategy. In absolute terms the safest strategy should be based on logical tests, but this is too demanding in terms of resources and timely calculations. Pilots compromise between risk and efficiency, basing the strategy on experience and redundancy. Second is

the problem of preparing responses to events. Again, pilots know that they will not have sufficient resources to find timely relevant solutions. They prepare these solutions far before action. All pilot activity is then directed to keeping the flight in the domain (normal and abnormal) which has been envisaged before the flight. Moreover, pilots organize activity in this domain to avoid transient situations in which prepared responses to events would not be applicable. (...) The primary qualities of the model of risk management are anticipation and action. Anticipation has no value if it is not accompanied with active behaviour forcing the actual to suit the anticipation model. The reactive model, because of resource constraints, is restrained to the minimum." (Amalberti, 1992, pp. 102-103)

He argues further that this way of dealing with risk is rendered more difficult by automation as transparency and flexibility are lost. Pilots react to this difficulty by either trying to outwit the technical system - e.g. entering non-existent wind into the computer in order for the computer to calculate a different, i.e. the desired, approach angle - or by fully delegating the responsibility to the technical system. For technology to support the pilots' ecological risk management, system designers would have to consider human situative problem solving strategies more instead of assuming prescriptive optimal strategies. An essential prerequisite would be to see humans more as a safety factor instead of solely as a risk factor.

#### **6.4 Assumptions about the nature of humans, technology and organization as a basis for system design**

The importance of implicit or explicit assumptions underlying system design that concern the role of humans and technology in the overall socio-technical system has been pointed out by Bailey (1989). He distinguished five such assumptions (see Table 1). Amalberti's argument goes further in assuming that by regarding the human as a risk factor and delegating all safety-critical functions to technology as the presumed safety factor, the human is actually turned into a risk factor. A self-fulfilling prophecy is created.

Allocation criterion	Implicit assumptions about the nature of	
	Humans	Technology
Cost efficiency	Cost producing factors	
Leftover	Disturbance and risk factor	Effectiveness and safety factor
Performance comparison	Competing factors	
Humane tasks	Valuable resource	Support for human operator
Flexible allocation	Valuable resources	

**Table 1. Criteria for human-machine function allocation and underlying assumptions (adapted from Bailey, 1989, and Wäfler et al., 2003).**

Methods like KOMPASS try to change assumptions about the nature of humans and technology in order to support the human as a safety factor. In doing so it is important to also question assumptions about organisations, i.e. "images of organization" (Morgan, 1986), especially assumptions concerning planning and control in organizations.

The tayloristic view on organizations presumes that at least the essential events and processes in an organization can be fully planned in advance and carried out as planned. Generally speaking this implies that organizations as fundamentally open systems can be turned into closed systems by adequate planning and control (cf. Weitz & Shenhav, 2000). Newer organization theory (e.g. Staehle, 1991; Thompson, 1967; Orton & Weick, 1990) emphasizes that uncertainties should not be avoided at any price, but that proactive handling of uncertainties needs to be supported in order to take into account the simultaneous rationality and indeterminacy of organizational processes. Abandoning the myth of full control permits constructive coping with the limits of planning, systematic support of decentralized autonomy, and deliberate choices between local and central control mechanisms. Disturbances are not taken automatically and without question as signs of bad planning and insufficient efficiency, but - also - as opportunities for individual learning and systemic development (cf. Grote, 1997).

### **6.5 The limits of control over technology**

For such a change in perspectives on humans, technology, and organization to take effect, another even more fundamental assumption is needed. This assumption states that even the most advanced technology would still be controllable by human operators if system designers and buyers of systems were willing to invest more resources in the development of these systems.

After decades of trying to develop theories and methods to affect such a change and as a consequence design better systems, the meagre overall success raises doubts about this assumption. What if the insufficient human control of technology is not caused by normative assumptions about humans, technology, and organizations, but by the factual restrictions on the controllability and more basically even the human imagination due to the ever increasing complexity of technology? Then either further technology development has to be stopped or the (partial) lack of control has to be accepted. Technically, this acceptance is equivalent to the determination of unmanaged residual risks. On the human side, there is hesitance to admit a lack of control due to problems of unmanaged responsibilities. The human operator is kept in the system as a backup where all problems come together and have to be handled. The fallibility of this approach and its abuse by system developers and the organizations operating the systems in order not to have to admit the lack of control has been pointed out by Lisanne Bainbridge (1982) with utmost clarity. Polemically one could argue that the current boom in research on trust in technology at the level of the concrete human-technology interaction (e.g. Muir, 1994; Moray, Inagaki & Itoh, 2000) has its roots in the fact that - while still acknowledging that control would be better than trust - trust is all that is left to the human operator. Experiments have shown technology is trusted when trust in one's own competences is low (e.g. Lee & Moray, 1992, 1994). From general psychology we know that self-confidence is strongly related to perceived personal control.

In the following, it is presumed that technology cannot be controlled fully by human operators. It is discussed how this presumption might change criteria for system design and how system design might benefit from this change in perspective.

## 6.6 Guidelines for the design of (partially) non-controllable technology

The main purpose of such new design guidelines would be to free the human operator of his impossible role of trying to fulfil stop-gap and backup functions in complex socio-technical systems. Methods supporting adaptive system design aim in a similar direction by allocating control fully and without human influence to the technical system in very stressful situations (e.g. Inagaki, 2000; Moray, Inagaki & Itoh, 2000). However, the crucial issue of responsibility is usually not dealt with in these methods.

According to Kornwachs (1999) the main prerequisites for taking on responsibility are the freedom to make choices and to act in the chosen manner. If people are forced to act in a particular way they cannot be held responsible unless they have brought this situation upon themselves. Also, he argues that missing knowledge concerning the action, its purpose and its consequences has to be available and attainable. He emphasizes that automation attempts to reduce complexity for the human operation in order to achieve these preconditions, but that at the same time new complexities are created which may violate these conditions.

Building on an approach which attempts to provide the preconditions for taking on responsibility and thereby also for control, the limits of control should also be defined as clearly as possible. In those areas which are classified as not controllable for the human operator, he cannot be held responsible. Taking the braking procedure in the Airbus A320 as an example, this would mean that the irreversible automation of the essential braking functions should be taught in pilot training and should also be indicated in the cockpit during landing. If mistakes happen in the execution of these functions, the system developer or possibly the organization operating the system should be held responsible, but not the pilots. Only if the pilots can be proven to have induced this situation deliberately or carelessly (e.g. due to insufficient competencies) in line with Kornwachs' argument, might they have to assume some of the responsibility.

During a recent workshop on the opportunities and risks of pervasive computing, similar arguments were raised, demanding that intransparency and uncertainty in technical systems should be made transparent by explicitly pointing them out (Meier, 2005). This could imply, for instance, that when switching on an RFID (radio frequency identification) application - such as the milk bottles in our refrigerator that order new milk when their use-by-date has passed - the user is informed about which network connections have been established and which of those are part of an unprotected network. Such indications do exist already for some internet applications. If the user still has the choice to not use the connection, the responsibility would rest with him or her. In cases where we are forced to use such connections, we would take note of the insecure status and thus lack of control without being able to influence the situation, but also without being held responsible.

In order to design socio-technical systems according to such guidelines, existing methods for assessing technical, human, and organizational risks should be extended to also indicate clearly zones of uncontrolled risks for both the organizations operating the system and the human operators at the sharp end. As much as possible even in these zones heuristics should be provided to the operator to help him or her cope with the uncertainties and to regain control. Process rules as defined by Hale and Swuste (1998) could be such heuristics. At the same time, in these zones the responsibility for the safe operation of the system would remain with the system developer and potentially the

system user, but not the human operator. The pressure to keep these zones small and thereby maximize control for the human operator would increase. Something similar is achieved already by US law allowing system operators to sue the system developer when his or her own erroneous action can be proven to be a consequence of bad system design (Baram, in press).

A method for risk analysis that could be helpful in this context is Hollnagel's CREAM approach (1998). This method distinguishes between four modes of control of the human operator: scrambled, opportunistic, tactical and strategic. These modes of control are assigned reliability intervals which are used to determine the probabilities of human errors in different event sequences. Such a differentiation might also be useful in identifying zones of lack of control for the human operator in a human-machine system, in which only scrambled control is possible, e.g. due to the unpredictability of consequences of a certain event. In system design, it would have to be decided whether functions in such zones could be fully automated and whether the human operator can be in any way supported in acting appropriately despite his or her reduced control. Instead of pretending that systems are safer than they are, due to their increasing embeddedness in complex networks, it may be a much better means to regain control by admitting to areas of intransparency and uncertainties in the system, as then coping can be trained systematically.

## 6.7 Final remarks

Much of what has been said in this paper is not new - however the underlying attitude may be new: Instead of lamenting the lack of human control over technology and of demanding over and over again that control be reinstated, the approach presented here assumes very explicitly that current and future technology contains more or less substantial zones of no control. Any system design should build on this assumption and develop concepts for handling the lack of control in a way that does not delegate the responsibility to the human operator, but holds system developers, the organizations operating the systems, and societal actors accountable. This could happen much more effectively if uncertainties were made transparent and the human operator were relieved of his or her stop-gap and backup function. This would also bring us closer to Kornwachs' (1999) requirement: Act in a way that keeps the conditions for responsible actions of all involved intact.

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## **7. GUIDA, GIOVANNI (WITH GIACOMINI, MASSIMILIANO; ROSSI, MICHELE & VIOLA, ANDREA); A KNOWLEDGE-BASED DECISION SUPPORT SYSTEM FOR CRISIS MANAGEMENT IN THE FIELD OF PUBLIC HEALTH**

### **7.1 Motivation**

The project discussed in this paper originates from a practical need. The management of large-scale emergency situations with an impact on public health is a complex and multifaceted problem. It involves several tasks and requires that several reasoning paths are carried out in parallel by the persons in charge of crisis management. Crisis managers operate at a coarse level; they are not involved in operative details, but have responsibility about high-level planning and allocation of resources. In particular, they have to deal with the following main aspects:

- acquiring and validating information from the field, about the originating events, their consequences, the actions undertaken to face the emergency situation and their effects;
- assessing the situation and identifying primary needs;
- identifying the most appropriate intervention plans and allocating human and instrumental resources to the activities to be carried out;
- activating the lower operational levels according to the identified intervention plans.

All these threads have generally to be carried out by a team of crisis managers, active 24 hours a day, even for rather long periods, who operate under pressure, stress, and responsibility overload. In their job, they have to exploit all available knowledge and experience, apply emergency plans, comply with general regulations, and promptly respond to the inputs arriving from the upper management at local, regional or national level.

In this context, a decision support system (DSS) would certainly be useful. However, this goal raises three main questions:

1. What is the core problem that crisis managers have to face in their job?
2. What are the main causes of complexity?
3. Which are the key decisions that must be made by crisis managers?
4. What type of support would be appropriate for them?

### **7.2 Methodological issues**

Answering the above four questions brings to light the main methodological issues behind the design of the DSS.

1. What is the core problem that crisis managers have to face in their job?

Certainly, the core problem is information overload. There is no structuring concept in the way crisis managers receive information from the field: information arrives at any time, uncontrolled, and unfiltered. Crisis managers receive a lot of information, but most of it is incomplete and provisional: new information may complement or even contradict the old one.

2. What are the main causes of complexity?

The complexity of the crisis managers' job primarily derives from the fact that they are involved in too many tasks at the same time. They have to take care of a very large

number of aspects that range from very important issues to trivial details. It is difficult for them to separate easy decisions that can be made on the basis of known, simple rules from complex decisions that require careful consideration and involve high responsibility.

### 3. Which are the key decisions that must be faced by crisis managers?

Crisis managers are faced with two types of decisions:

- Which action plan to apply in response to an event?
- How to allocate the available resources to the actions of the active plans?

### 4. What type of support would be appropriate for them?

Neither an informative nor a normative approach would be definitely appropriate to support the crisis managers in their job. Informative support would be certainly useful in providing a structured, clear and focused representation of the events, but in the end it would turn out to be weak and unable to cope with the complexity of the problem. Normative support is simply impossible, due to the variety of situations that may arise and to the fact that crisis managers are personally responsible of the decisions they make.

## 7.3 The focused approach to decision support

In this context, a novel approach to decision support has emerged, called a focused approach. A deep analysis of the application domain has revealed that the majority of decisions that have to be made by crisis managers are not critical and can be made on the basis of available domain knowledge; only a small number of decisions are really critical and require the attention of crisis managers. Therefore, the following schema to decision support has been identified:

- Non critical decisions can be supported through a normative approach. In fact, existing regulations, stated emergency plans and available experience of previous cases provide a rich and reliable knowledge base for decision making.
- This way, crisis managers are allowed to focus only on critical decisions that definitely require their intervention. Therefore, their cognitive resources are not dispersed among a number of trivial choices, but are focused on a small set of crucial aspects, namely: the selection among alternative intervention plans and the allocation of resources.
- For all critical decisions crisis managers receive an informative, structured decision support. The decisions to be made are presented in a disciplined and clear way and are supported by additional specific decision information useful to identify and rate possible alternatives.

## 7.4 Organization issues and design criteria

Crisis managers have been partitioned into three professional roles:

- Information managers, in charge of collecting and validating data and information arriving from the field;
- Resource managers, in charge of monitoring data about available resources to be used in crisis management;
- Decision makers, in charge of high-level decisions necessary to manage the emergency in the most suitable and effective way.

The DSS provides specific support to all these categories, through dedicated views. Information managers interact with the DSS through an event frame that supports them in the analysis of incoming data and in their correct representation through the system interface. This way, all relevant events occurring in the field are taken in input by the system, after necessary validation. The event frame also reminds information managers about expected events and prompts them to undertake the necessary investigations in case they fail to manifest.

Resource managers operate through the resource frame that supports them in the real time updating of the database of available resources, both human and instrumental.

Decision makers work in parallel with two frames (presented on separate screens). The plan frame presents to the decision makers the plans that should be activated in front of the occurred events, and helps them to make decisions about possible alternatives to be chosen during plan execution; to this purpose, alternatives are analyzed by the DSS according to stated criteria and ranked accordingly. The action frame helps the decision makers to allocate available resources to the actions of the currently active plans, in such a way as to avoid that actions might be started without the minimal necessary resources and to support effective load balancing.

This organizational setting turned out to be the minimal one to support this complex task.

## **7.5 Implementation and experimentation**

The decision support system is presently under development. A first prototype will be completely running by the end of 2005 (a first version is already available), designed to run in a distributed environment, and developed in Java environment (with open source software components). It deals with an earthquake scenario and concerns three sample cases, chosen to demonstrate system potential, namely: possible pollution in the aqueduct of a town, damages to a high-risk factory that might cause an environmental disaster, unavailability of regular home assistance for patients requiring special care.

## **7.6 Limitations of decision support and an approach to robustness**

Clearly, the capabilities of the DSS strictly depend on the ability to model a large set of possible cases and events, as well as on the availability of knowledge to deal with them. The DSS operates on the basis of compiled knowledge (it does not rely in first principles or deep models of the domain, to a large extent simply impossible to elicit): effective and correct operation ends exactly where knowledge starts to be lacking.

The capabilities of the DSS can be compromised in at least two cases: not only when the occurring events are not covered by the available knowledge base, but also when the crisis managers do not accept the prescriptions or the suggestions of the system and make decisions strongly contrasting with the DSS model of reasoning. In both cases the system becomes rapidly unable to react to further inputs and can not control the evolution of the emergency situation any more.

To improve the robustness of the DSS, two strategies are envisaged. At a first level, the DSS is programmed to point out to the user the case when it starts operating at the limits of its competence domain and, therefore, its advice is becoming more and more unreliable. Furthermore, after this point has been trespassed, the system can change its state and start working according to an experimental schema, where the decisions of the user overwrite system knowledge and become the basis for future DSS operation. The

system tries to apply its own knowledge as far as possible and, when it turns out to be inapplicable, it resorts to new knowledge directly derived from recent user interactions. This way, new knowledge is accumulated during experimental operation that can later be analyzed and – if appropriate – used to expand the permanent knowledge base of the DSS.

## 8. HOFFMAN, ROBERT: POSITION STATEMENT

1. Cognitive Systems Engineering has matured to a point where it is feasible to commence a collaborative effort to forge a unified Theory Of Complex And Cognitive Systems (TOCACS). (See the Bibliography.)
2. Version 1.0 consists of postulates that fall into classes including: A Metatheory, Laws of Cognitive Work, Design Challenges, and Measurement.
3. The Metatheory asserts a systems stance. It specifies ways in which postulates can be refuted and inferences from the theory can be disconfirmed (via "forced inconsistency"), and it includes postulates concerning completeness and consistency.

The metatheory specifies what is meant by "law."

- The laws within the theory have mnemonic value, they express cautionary tales, and they are empirical generalizations.
- But they are more than this: They are extensional (i.e., they refer to classes) and nomological generalizations (i.e., they are universal given certain boundary conditions).
- The issue then is how they can be inviolate. This is where a notion of "goodness" plays a critical role in the theory.
- The metatheory cannot be carved away from the Laws. For example, the teams of people and machines that design CACSs themselves constitute a CACS, and so are prone to reductive explanation tendencies and the trap of designer-centered design (e.g., The road to user-hostile systems is paved with user-centered intentions).

4. The Laws of Cognitive Work specify the empirical regularities in terms of families of functions, including:

Forces that promote stability and resistance to change

- e.g., The Penny Foolish Law: Any focus on short-term cost considerations always comes with a hefty price down the road, that weighs much more heavily on the shoulders of the users than on the shoulders of project managers.
- e.g., The Cognitive Vacuum Law: When working as a part of a CACS, people will perceive patterns and derive understandings and explanations, and these are not necessarily either veridical or faithful to the intentions of the designers.
- Forces that lead to instability and momentum
- e.g., The Law of Stretched Systems: CACSs are always stretched to their limits of performance and adaptability. Interventions will always increase the tempo and intensity of activity).
- e.g., Rasmussen's Law: In cognitive work within a CACS, people do not conduct tasks, they engage in context-sensitive, knowledge-driven choice among action sequence alternatives.

- Forces that contribute to (or detract from) alignment or coordinative symmetry.
- e.g., Dilbert's Law: A human will not cooperate, or will not cooperate well with another agent if it is assumed that the other agent is not competent.
- e.g., Mr. Weasley's Law: Humans should be supported in rapidly achieving a veridical and useful understanding of the "intent" and "stance" of the machines.

5. The Design Challenges are entailed by the Laws, and specify the features of the "good" CACS.

- These are offered as candidates for adoption as design policies in procurement.
- e.g., The Sacagawea Challenge: The good CACS supports active organization of information, active search for information, active exploration of information, reflection on the meaning of information, and evaluation and choice among action sequence alternatives.
- e.g., The Pleasure Challenge: The good CACS instills in the humans a feeling of direct engagement. They simultaneously provide a feeling of flow and challenge.
- The notion of goodness will be critical to the theory, and is anchored in additional postulates concerning measurement.

6. Many of the TOCACS postulates have Corollaries.

Example: Corollary to Rasmussen's Law: When it appears as if people are conducting tasks, that is either because the activity is routine and requires no choice, or because a task procedure is mandated.

7. Finally, the postulates in TOCACS have multiple entailment relations with one another. They "hang together" in necessary, interesting, and useful ways.

- Example entailment:

The Gödelian Postulate: TOCACS is necessarily incomplete.

The Reductive Explanation Law: In the struggle to assimilate new knowledge, explanations (at any given time) will inevitably involve simplifications.

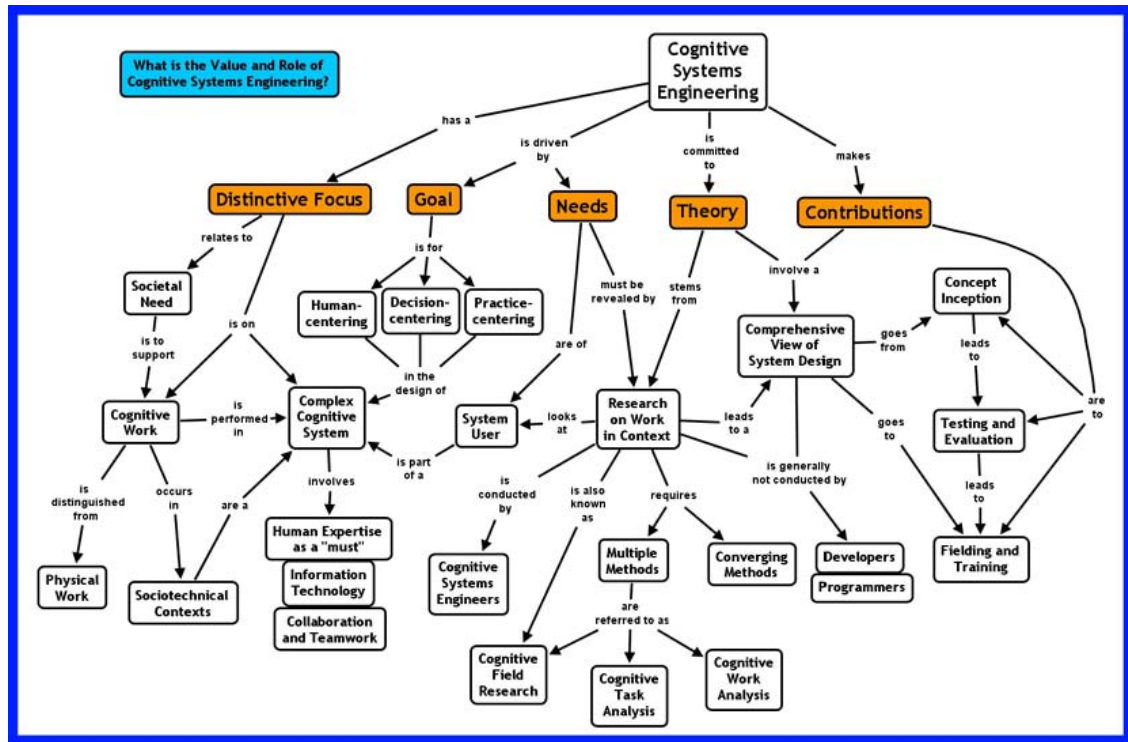
- Example entailment:

Envisioned World Law: New technologies are hypotheses about how work will change.

Moving Target Law: The context of cognitive work is itself always changing.

- The entailment relations point to interesting ways in which the Laws interact, and some provide necessary and strong linkages between the metatheory and the other classes of postulates. They also help justify the claim that the postulates in TOCACS, as a set, constitute a scientific theory.

8. Development of the theory will require a continuing collaborative effort; the theory will be periodically updated and refined.



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## 9. HOLLNAGEL, ERIK: DIMENSIONS OF DECISION-MAKING - WHAT, HOW AND WHEN

Decision-making has traditionally been about choosing an alternative, i.e., what to do in order to ensure that a desired outcome obtains. This tradition is usually associated with Blaise Pascal and the invention of probability calculus, but can be found even earlier. It may even be seen as having roots in the general human need to attain desired outcomes in life – and in what may come after that. Decision theories have therefore very much been concerned with the ‘what’ of decision-making and there is not shortage of recommendations – or even norms – on how to make the right decision.

Decision-making is in practice, however, also very much a question of how to do things and when to do them. The ‘how’ can in the manner of recursion be seen as a decision about what the right means of implementation are, although that in itself is not independent of the choice of alternatives in the first place. Information about how alternatives can be realised may thus be considered an additional dimension to the utility, which in one form or another is supposed to affect or even determine choices. This can lead to interesting discussions of how the values of alternatives can be established in the first place.

The ‘when’, on the other hand, cannot be subsumed by the common decision-making paradigms in the same easy manner. Indeed, many decision models and decision-making theories seem conveniently to disregard the existence of time or at least to make the assumption that decisions are made so quickly that changes in the environment are of no consequence. Decision-making is thus considered as a process in individuals or organisations rather than an activity.

However, if we consider decision-making as an activity in the manner of ‘naturalistic decision-making and ‘cognition in the wild’ rather than as a ‘rational’ process, a number of the traditional assumptions have to be discarded, for instance:

- Decision-making is not a discrete and identifiable event, but rather an attribution after the fact. That it is possible to look back at a specific event or activity and identify parts where a decision ‘must’ have been made, does not necessarily mean that the people who were involved made an explicit decision at the time.
- Decision-making is not primarily a choice among alternatives. It is very difficult in practice to separate decisions from what is otherwise needed to achieve a decision-maker’s objectives. Although a decision cannot be made without some information about the situation, the demands, and the possibilities of action, the quality and quantity of that information may indirectly favour one outcome rather than another. In most cases a decision also requires actions to ensure that the expected outcomes obtain. It is therefore arbitrary to restrict the term decision-making to the ‘moment of choice’ and disregard what goes on before and after.
- Decision-making is usually not a distinct event that takes place at a specific point in time, or within a certain time window and which therefore can be dissociated or isolated – even if ever so briefly – from what goes on in the environment.

There are some really fundamental problems arising from the fact that decision-making as an activity takes time and therefore requires that the information it uses remains valid

while the decision is made. (This is, of course, not only a problem for decision-making but for all human actions.) Yet despite the importance of time few models of either decision-making – or of human behaviour in general – have taken that into account. In the view of cognitive systems engineering, decision-making is a part of how people try to cope with a complex and dynamic environment, and is therefore an issue about how and when to do something, as much as an issue about what to do.

In consequence of this, the issue of decision support changes completely. First of all it is not just an issue of automation, since decision-making cannot be automated without ceasing to be decision-making. Whereas automation is feasible for situations that are highly regular, hence can be analysed completely in advance, decision support is needed for situations that are irregular and unpredictable, which makes prior analyses difficult or impossible. The support must first and foremost be closely integrated with the task and therefore be continuous rather than discrete. Any discussion about ‘intelligence’ in decision support must also change. Since the intelligence clearly cannot be in the support but must reside in the decision maker (as an individual or a group), we should strive to support intelligent decisions and intelligent implementations rather than build intelligent support systems. In that sense the implementation issues (‘how’, ‘when’, etc. rather than ‘what’) become issues of maintaining control, and of regaining control if it is lost, rather than of supporting decision making as a mental process.

## **10. INAGAKI, TOSHIYUKI: VIEWPOINTS FOR DESIGNING HUMAN INTERACTIONS WITH INTELLIGENT AND AUTONOMOUS MACHINES**

Various efforts have been exerted to improve safety of transportation systems, such as aircraft, automobile, railroad, and marine vessels. Accidents rates, however, are not low enough. One of the reasons may be that advanced functionalities and speeding up of those transportation systems impose human operators excessive claims on their abilities for situational recognition, decision-making, and action implementation. Another reason may lie in autonomy and intelligence of operator support systems. Intelligent machines can sense and analyze situations, decide what must be done, and implement control actions. Humans working with such intelligent machines often suffer negative consequences of automation, such as the out-of-the-loop performance problem, loss of situation awareness, complacency or over-trust, and automation-induced surprises.

Human-machine collaborations may be heavily dependent on the transportation modes. Some viewpoints are necessary to identify what functionalities are required for operator support. I would like to discuss two of those viewpoints: (1) quality of human operators and (2) time-criticality.

Quality of human operators varies depending on modes of transportation. For non-professional operators, such as private car drivers, it is not appropriate to assume that they have high level of knowledge and skills, or thorough and continual training, which implies that required driver assistance functionalities may be quite different from those for professional operators, such as airline pilots or train drivers.

Time-criticality also differs appreciably depending on transportation modes. Suppose a warning has been set off. If it was a resolution advisory (RA) of traffic alert and collision avoidance systems for aircraft, the estimated time to closest point of approach must be 15 to 35 seconds, and pilots are supposed to respond to the RA within 5 seconds. If it was a collision warning on the car, on the other hand, it may have been given just a few seconds prior to a possible collision.

Noting the above two points, I would like to discuss how we should design functionalities for assisting human operators appropriately and context-dependently. Discussions may be made on two aspects: Enhancement of situation awareness, and design of authority.

Human interface design is central for enhancing situation awareness, avoiding automation surprises, establishing appropriate trust in automation. The implemented human interface must enable the human to: (1) Recognize intention of the automation, (2) Understand why the automation thinks so, (3) Share the situation awareness with the automation, and (4) Show limits of functional abilities of the automation. The enhancement of situation awareness matches well with the human-centered automation concept, in which human locus of control is claimed.

On the other hand, design of authority may claim that the final authority should be shared between humans and machines in a context-dependent manner, which may sometimes conflict with the human locus of control principle. However, high level of automation (LOA) may be vital for assuring systems safety. I will show three approaches for choosing an appropriate LOA by predicting how the LOA may affect humans and change their behaviors.

## **11. JOHANSSON, BJÖRN: COGNITIVE CONTROL TOOL - A REFLECTION ON THE TERM “INTELLIGENT DECISION SUPPORT SYSTEM”**

### **Abstract**

Below, we will argue that the term “Intelligent Decision Support Systems” is misleading and should be replaced with a new term. The following arguments are presented: 1.) it is unclear what is meant by intelligent, and in what sense a decision support can be intelligent, 2.) decisions are important, but it is not justifying to call it decision support, since the decision actually only is a very limited part of the control task, 3.) “support system” indicates that only a certain part of the control system is supported, but the way we use the term is too vague. From literature, it seems that everything from presenting data to full automation is seen as decision support.

To avoid confusion, a new term that takes a stance in the purpose activity (control) rather than a vague notion like intelligence, and that avoids the focus on a specific step (decision making) in that task is suggested. The term “Cognitive Control Tool” (CoCoTo) is suggested. A cognitive control tool is a tool that is designed to increase one or more of the cognitive functions of a controller (observation, identification, evaluation, decision, planning). In order to create a cognitive control tool, the goal of the task must be understood, as well as the limitations in human handling of the task.

### **11.1 Intelligent Decision Support Systems**

Within the field of Intelligent Decision Support Systems (IDSS), we are interested in a wide range of systems that, based on models of human cognition, provides support for decision in various forms, ranging from suggestions of actions to pure information presentation. The types of tasks that the IDSS is designed for may also range from expert systems to systems focusing on information presentation, demonstrating that the underlying models and available data in the IDSS vary greatly.

The common reference is (or, perhaps should be) that all systems labeled “intelligent decision support” have been built with the purpose of guiding a human decision maker during a cognitively demanding task. If the system is used it, in a sense, becomes a part of the operator’s cognition, since it affects the decisions, and consequently actions, that the operator chooses. The IDSS thus becomes a part of the cognitive system, a cognitive system with its own intentions and goals, although these intentions have been built into the system by someone else. The IDSS simply turns into a part of the controlling system, and indeed an essential part.

### **11.2 What do we mean by “intelligent”, “decision” and “support”?**

The term “intelligent decision support” is somewhat fuzzy. During the last meeting in 1985, there seems to have been difficult to conclude what really was meant by the term “intelligent decision support”. Duncan (1985) writes in his summary of the panel discussion on cognitive engineering that

“Not unpredictably, there was little enthusiasm to define the intelligent component of decision support ... Ultimately the goal is not so much to build an ‘intelligent’ aid as it is to build an aid that helps the human act

more intelligently.”  
(Duncan, 1985, pp 447)

The last sentence is however recursive in the sense that it does not explain “intelligent” by any other means than reference to the term itself. Hollnagel, Mancini & Woods makes an effort to establish a functional view on intelligence in the concluding chapter of the book.

“Referring to a Man-machine System as being intelligent certainly implies that there is something in it over and above human intelligence; otherwise every system that included human beings – as most systems do – would deserve the label ‘intelligent’...

However, even if we do not know exactly what intelligence is, we know how it functions and what role it plays in dealing with process environments as well as in daily life. We can therefore from a purely functional understanding improve the conditions for use of human intelligence by amplifying its effect on the environment.”

(Hollnagel, Mancini & Woods, 1985, pp 465-466).

Two important points occur in this quote. In the first sentence, the authors note that the term “intelligent” suggests that a system with an IDSS must be something more than a system without IDSS. In the second sentence, they admit that there is an uncertainty in the actual meaning of the term intelligent, but still suggests that it could be understood in terms of amplification of the effects of it. It is a somewhat problematic statement since it still does not help us to understand what intelligent means. Another view of “intelligent” in relation to IDSS could naturally be that the system adapts to the operator or to changes in the environment. The term used to describe such systems today is “adaptive”, and that is probably a more reasonable notion.

A quick browse in some dictionaries is not very helpful either. The term intelligent “stresses success in coping with new situations and solving problems”<sup>1</sup> or, “revealing or reflecting good judgment or sound thought”, alternatively “the ability to learn, understand and make judgments or have opinions that are based on reason”<sup>2</sup>. Similar definitions appear in most dictionaries. It seems as if there is some kind of agreement upon definition that intelligent means “having the capacity to understand a situation and reason in a rational way to find the best way to handle it”, like in normative decision making.

This brings us to the next question. What do we mean by the term “decision”? Many directions, for example dynamic decision making (Brehmer, 1992) or Naturalistic Decision Making (NDM, Klein et al, 1993; Klein, 1998) focus on the process of making

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<sup>1</sup> Merriam-Webster Online dictionary, <http://www.m-w.com>

<sup>2</sup> Cambridge Advanced Learner’s dictionary <http://dictionary.cambridge.org/>

decisions. Decisions are an important part of a controlling task. Much of our basic knowledge about decision making is based on research on “toy” examples, mainly concerning controlled problems where it is possible to determine whether there is a solution to the problem or not. In such examples, researchers often aimed at examining if subjects are able to find the “best” solution in a normative sense (for example the tower of Hanoi, Simon 1975). This view is called normative decision making.

There are some basic assumptions about the rational decision-maker such as that the decision-maker is completely informed, is infinitely sensitive and always rational. Today we know that not even when the two first assumptions are fulfilled, it is not guaranteed that the decision-maker acts rationally. The most important criticism against the rationalistic view has been presented by the natural decision making-paradigm<sup>3</sup> (Klein, 1998). Researchers like Klein et al. (1993) and others have suggested that real-world decision making is a fundamentally different task than the tasks that have been examined in traditional problem-solving/decision-making research. Real-world decision-making is usually faced with ill-defined goals, a large and very complex problem-space, lack of time and other aspects that create uncertainty (dynamic situations). There are several models of decision making available today, but most of them share the following components. First, a decision has to be activated, i.e. there must be a need of making a decision. A typical example would be if some kind of alarm sounds off in a nuclear reactor control room. The first thing that the operators would need to do is to identify the source of the alarm. After this, he/she evaluates the effects of the identified alarm. Which action should be taken? The operator must make a decision. The decision may then have to be planned, depending on the goal of the decision, before it can be executed.

As described in the paragraph above, as well as in most literature concerning decision support systems, the “decision” is in focus. But what do we really mean by the term decision “support” in this case? Dekker & Woods (1999) has (based on Sheridan’s work) proposed 10 levels that can be used to classify a support system (originally levels of supervisory control):

1. offers no assistance,; human supervisor must do it all;
2. offers a complete set of action alternatives, and
3. narrows the selection down to a few, or
4. suggests one, or
5. executes that suggestion if the supervisor approves, or
6. allows the supervisor a restricted time to veto before automatic execution, or
7. executes automatically, then necessarily informs the supervisor, or
8. informs him/her after execution only if he asks, or
9. informs him/her after execution if the subordinate decides to

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<sup>3</sup> Although the fact that decision-making rarely is based on rational reasoning has been known for a long time, see for example Lindblom (1959), or Dörner (1989).

10. decides everything and acts autonomously, ignoring the supervisor.

(Dekker & Woods, 1999, pp 88)

In the case of IDSS, a system performing in accordance with points 7-10 does more than supporting a decision, the system actually executes actions and is thus more of an automat, or a controlling system than a “decision support”.

### **11.3 Decisions and control**

The step from decision to execution is crucial if we want to understand what an IDSS really is designed for. To only discuss decisions is too hypothetical to be meaningful since the actual task that is at hand is control. In this paper, a cybernetic perspective on control is used (Ashby, 1956). Control is the task of affecting a target system state with the goal of reaching/maintaining a state desired by the controller. Thus, a decision, even if correct, does not lead to control unless it is followed by an action affecting the state of the target system. As follows, the purpose of control (and thus action) is to either change or maintain a state in the target system.

### **11.4 Discussion – Cognitive Control Tools**

So, what is it really an IDSS and what is supported by it? It seems clear, both from the descriptions of IDSS in the proceedings from the 1985 meeting and actual systems today, that such systems actually “supports” a range of activities. Decision making is only a part of the cognitive functions involved in the control process, which in its most basic form can be described as monitoring, detection, evaluation, decision and action. The underlying assumption with IDSS seems to be that if we can support a decision, we will also enhance control and performance. If that is the point, it would be more justified to say that we support control rather than decisions.

However, the term “support system” is problematic in another way as well since support can be performed at a number of levels (see Dekker & Woods, 1999, above). If we take a stance in the ten levels, we can see that a decision support can be practically anything from pen and paper where to-do notes are made to a fully automated control system. What seems more appropriate is to firstly find a term that describes the fact that the support is manifested in the form of a man-made artefact specifically designed with the purpose of increasing control. A term that is commonly used is tool. The term tool indicates that we are discussing an artefact that is adding something to the unaided capability of the human operator. It also suggests that what is added is designed for a specific task, and that there is a difference between performing the task with or without the artefact. Further, it avoids some confusion associated with the use of “system”. When, as for example in Cognitive Systems Engineering (Hollnagel & Woods, 2005), an operator and the tools he/she is using is viewed as a cognitive system, the status of an “Intelligent Decision Support System” is somewhat unfortunate, since it suggests that there is a intelligent, or cognitive, system in the system, thus ascribing cognition or

intelligence to the technical system in it self<sup>4</sup>, while the actual foci should be on the human and the system as a joint cognitive system (Hollnagel & Woods, 2005).

The term “intelligent” used in combination with decision support seems to have been problematic already at the 1985 meeting since most contributions to the proceedings either avoid it or admit that they lack a satisfying definition, and the confusion associated with the term has already been discussed above. However, we can conclude that what we want to improve is a cognitive task with the goal of controlling a target process. Such a task involves both higher and lower levels of cognition, like monitoring, detection, decision-making and planning. We therefore suggest the following reformulation of IDSS; “intelligent” should be replaced by cognitive, “decision” should be replaced by control, and finally, “support system” should be replaced by tool, ending up with the term Cognitive Control Tool, (CoCoTo).

A Cognitive Control Tool is more than a suggestion for a re-definition of the term IDSS. The way it is defined actually allows us to derive some (very general) guidelines for design of such a system:

First of all, it is a cognitive tool, meaning that the tool should be used for improving/amplifying one or more basic cognitive tasks. A model of cognition and control should thus be used as a point of departure. In this case many different models of cognition and control could be used for identifying the task, as long as the model incorporates the basic cognitive components of control (monitoring, detection, evaluation, decision and planning).

Secondly, the specific control activity/process that the tool is intended for has to be understood. Is the usage of the tool mainly induced by changes in the environment/target process (a reactive task, focusing on regulation), or is it a task that is mainly induced by the controller (a planning task, focusing on strategies/tactics), or perhaps both?

Thirdly, the specific setting (context) of use has to be understood, just like in the design of any tool. The working context generally incorporates some specific characteristics that can only be understood by studying the physical work space and the specific behaviours of the operators working in that setting.

Labelling the area of interest as Cognitive Control Tools will not solve any of the problems that earlier research on Intelligent Decision Support Systems has encountered, but it might help us avoid some of the confusion that is associated with the earlier term. The field concerned with creating tools designed to improve performance in cognitive tasks like monitoring and decision making have always been multi-disciplinary by necessity, but the diverse points of departure (psychology, computer science, HMI, cybernetics etc) have lead to problems in agreeing on both the purpose of such systems

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<sup>4</sup> A technical system can be seen as a cognitive system depending on the definition of cognition that is used. This is however not appropriate when it concerns tools meant to be used by humans, since they then should be incorporated in the analysis of the joint system.

and how they should be designed. By using a more clear terminology, that takes a stance in the development of tools that can be used for cognitive control tasks, there are at least a chance to reach a consensus about what we discuss, which may enhance collaboration over the fields.

### **11.5 Acknowledgments**

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## **12. KRAEMER, SARA & CARAYON, PASCALE: INFORMATION DECISION SUPPORT SYSTEMS IN COMPUTER AND INFORMATION SECURITY**

Over the past several decades, computer and information security (CIS) and its related problems, such as the security breaches, attacks, and incidents, have adversely affected business, commerce, and the nature of work. The 2005 Computer Security Institute/Federal Bureau of Investigation (CSI/FBI) reports data from 699 respondents from U.S. corporations, government agencies, financial institutions, medical institutions and universities (Gordon, Loeb, Lucyshyn, & Richardson, 2005). Some \$130 million dollars were accounted for total losses from computer security incidents (Gordon et al., 2005). The survey found the following trends in CIS: (1) 56% of organizations reported unauthorized use of computer systems in the last 12 months; (2) 9% reported experiencing more than ten computer security incidents in the past year; and (3) 95% experienced ten or more Web site incidents in the past year (Gordon et al., 2005).

The security community has largely focused on the technical causes of security breaches or vulnerabilities. It has been argued that the human factor that is associated with the use and design of security is largely ignored by this community (Sasse, Brostoff, & Weirich, 2001). The poor implementation of security can seriously impact an organization's productivity, reputation, and the well-being of its employees. The implication is that while human side of computer security is almost always exploited, such as a user error, the blame is not of the users but rather the factors of the work systems in which they work. Even with a strong, technology-centered approach, many exploits can and will be facilitated by user behavior (Besnard & Arief, 2004; Carayon & Kraemer, 2002; Schein, 1984) or faulty operational, management, or organizational factors (Computer Science and Telecommunications Board-National Research Council, 2002).

When thinking about a CIS system, end users and network administrators or information technology professionals differ in terms of their needs and technical expertise (Kraemer & Carayon, 2005). End users may have minimal direct impact on actual or potential vulnerabilities and breaches in security. Firewalls, authentication systems, and access levels are typically set up to prohibit end users from obtaining root-level access and inadvertently causing a breach in security. However, end users may still contribute to vulnerabilities within the work system. For example, their noncompliance with security policies and procedures may result in vulnerabilities, compromises, and breaches of security. On the other hand, network administrators and other information technology professionals are the designers and implementers of security technologies and systems, and therefore have a direct impact on the level of protection of a computer and information system.

### **12.1 Needs of various computer and information security user groups**

The purpose of this position statement is to outline some of the dimensions of needs and possible 'outcomes' for various groups that interact with computer and information systems and that affect their security. Our second purpose is to highlight possible applications and benefits of information decision support systems (IDSS) in CIS systems. In this context, we have identified two groups: network administrators, those who design, build, and maintain CIS systems and end users, those who interface with CIS technology, rules, policies, and procedures in order to carry out their work. We

have made the distinction between these two groups because of their varying influence on the state of the CIS system: a network administrator has the ability to change, edit, and build CIS systems, while end users interact with the technology, policies, and procedures that have been determined by the network administrators and other system managers. Some possible dimensions of the various interactions between a user and a CIS system are the following:

- Attitude: the emotion or feeling toward CIS
- Behavior: the way in which the user conducts themselves in response to CIS initiatives, programs, technology, policies, other users, etc...
- Motivation: reasons for user behavior toward CIS
- Needs: necessary requisites for a user to perform their work and maintain proper security levels

It is important to consider these dimensions because there are various workplace factors that affect behavior, and therefore different mechanisms to support network administrator end user behavior. In order to examine some of these issues, we interviewed eight network administrators at two computer science laboratories at a large university and eight security managers in seven private industries on the various types of human error in CIS, committed by both network administrators and end users, as well as the various workplace factors that affect the occurrence of human error in the CIS context (Kraemer & Carayon, submitted May 2005). In another study of a workgroup of six CIS managers and specialists, we identified eight major human and organizational factors that are associated with specific CIS vulnerabilities (Kraemer & Carayon, submitted January 2005).

In these efforts, we identified human and organizational factors issues that are different for network administrators and end users. For example, network administrators typically have a high workload that prevents them from adequately monitoring and maintaining the appropriate patches for their respective CIS systems. Some of this is due the current state of CIS: CIS patches are not systematized into one central location or method, network administrators have to search websites and email for alerts, or rely on word of mouth. Coupled with a high workload and unruly system for monitoring and applying patches, many times vulnerabilities are missed or not fully applied. For end users, the challenges are different. Since their principle behaviors center on the interaction with CIS technology, policies, and procedures, the usability of the various mechanisms used to support CIS becomes an issue. Consequently, the end user may adopt a series of violations or 'work arounds' in their tasks and work efforts. Despite these behaviors deviating from mandated CIS procedures, their actions do keep certain levels of CIS system status. Therefore, there are opportunities to create support systems for network administrator and end users.

## **12.2 IDSS in computer and information security**

There are some possible beneficial applications of IDSS in CIS. Research in the area of computer and information security is young and underdeveloped, and are not to the levels of sophistication that are found in safety in aviation, the nuclear power industry, or the transportation industry. Some possible directions for the development of IDSS and CIS are the development of tools to support CIS tasks and user behavior. In order to develop these areas, we have conducted some preliminary trade-off analyses to determine the benefits and challenges faced between current automated or simulation CIS methods and human performance from a red team (Carayon & Kraemer, 2004). We

have collaborated with Sandia National Laboratories' Information Assurance Red Team (IDART) program to determine a set of trade off factors. Red teams are 'hackers for hire' or systems security analysts that are hired by organizations to penetrate their CIS system defenses, break into their systems, and provide feedback on their vulnerability state(s). In this study, we conducted semi-structured interviews with 15 red team members and two focus groups to determine the tradeoffs between automated or simulated security methods versus red teaming. The interviewee responses are summarized in Table 1.

Table 1. Summary of responses on the tradeoffs between automated or simulation CIS methods and red teaming by the IDART members

Weaknesses of automated or simulation methods	Strengths of automated or simulation methods	Strengths of red teaming
<ul style="list-style-type: none"> <li>-Humans are superior at connecting data into useful information (7 comments)</li> <li>-Lacks human cognition abilities (2 comments)</li> <li>-Lacks social engineering abilities (2 comments)</li> <li>-Does not have the capabilities to address the complexity of systems (2 comments)</li> <li>-Does not address the unpredictability of computer systems (1 comment)</li> <li>-Does not address the changing nature CIS (1 comment)</li> <li>-Lacks the ability to assess the worst-case scenario for the system (1 comment)</li> </ul>	<ul style="list-style-type: none"> <li>-Good at testing a set of known vulnerabilities (3 comments)</li> <li>-Useful for compiling a database of red team findings (2 comments)</li> <li>-Useful in simple, single-purpose environments, such as isolated sections of an information system (1 comment)</li> </ul>	<ul style="list-style-type: none"> <li>-Red team tactics are "ahead of the curve" in hacking world (3 comments)</li> <li>-Red team methods are creative (3 comments)</li> <li>-Able to respond dynamically to changes in system states (2 comments)</li> <li>-Produce a specified system analysis (2 comments)</li> <li>-Write specific tools to aid in targeting vulnerabilities (1 comment)</li> <li>-Able to find patterns in data (1 comment)</li> </ul>

From the red team perspective, there are possibilities for the design of support systems for CIS. A red team assessment of a CIS system particularly useful for targeted assessments, using cutting-edge technology, and benefiting from the synergy of a high-performing team. Their assessments are characterized as creative, specific, and dynamic – and almost always lead to better and more thorough assessments than an automated or simulated method. Given these tradeoffs, it appears that there is opportunity to glean the capabilities of a red team to create support systems for CIS.

### 12.3 Acknowledgements

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### **13. LIND, MORTEN: A CONTROL AND SYSTEMS ENGINEERING PERSPECTIVE ON MEANS END ANALYSIS OF WORK DOMAINS**

#### **Abstract**

Work domain analysis using means-end analysis (MEA) is one of main ideas of Cognitive Systems Engineering (CSE). It is suggested that a representation of the work domain by means-end concepts is a suitable basis for designing the information content of human machine interfaces for supervisory control (Rasmussen and Lind, 1981). It has been one of the aims of the CSE research community within the last two decades to explore, develop and demonstrate this idea. Especially Rasmussens abstraction hierarchy (AH) has been used (Rasmussen, Pejtersen and Goodstein, 1994) and more formalized modeling approaches like multilevel flow modeling (MFM) has been developed (Lind, 1994 and 1999). But as with other innovative ideas, the idea of using means-end concepts for human machine interface design is based on several claims and assumptions. Until recently only little attention has been devoted to an examination of these claims and assumptions. In the paper we will identify some of the claims and assumptions and discuss their validity from the perspective of control and systems engineering. We will also identify some of the challenges facing current research in the area.

#### **13.1 Introduction**

We will discuss the following two claims, which we believe motivate the use of means-end analysis in CSE.

Means end concepts and analysis

- can be used as a common basis for design of the human machine interface and the automation
- represents the constraints of the work domain which are relevant for the operators in supervisory control tasks and does it independently of specific fault situations

It is also claimed that means end concepts have cognitive validity by reflecting basic modes of human understanding of the intentional structures of the physical and social environments. Presentation of information based on these concepts in the interface would therefore be intelligible to an operator and thereby contribute to making the supervised system transparent. The relevance of means-end concepts for human cognition is confirmed by the work of Duncker (1945), Newell and Simons research in human problem solving (Newell and Simon, 1972) and by studies of fault finding by technicians in electronics workshops.

It is actually the combination of this claim with the other claims mentioned above that makes CSE an attractive framework for HMI design. However, a detailed discussion of the relevance of means-end concepts for human problem solving is outside the scope of the present paper. In the following only the first two claims mentioned above will be discussed.

#### **13.2 The Relevance of MEA for Systems Design**

It is often claimed that means-ends analysis of the work domain can be used as a basis for an integrated design of the human machine interface and the automated systems.

One of the problems of traditional HMI design is that they are designed too late in the systems design process. Factors related to human cognition and problem solving are therefore not taken properly into account in the design of the automation leading to suboptimal allocation of control tasks between the human and the machine. But we have found that work domain analysis by means-end concepts does not integrate very well neither with current systems design processes in automation industry nor with mainstream concepts of control theory.

### *13.2.1 The Systems Design Process*

Industrial engineering of control systems is based on diagrammatic representation of the process and the automation system in the form of process flow diagrams depicting material and energy flow paths and process and instrumentation diagrams showing relationships between process components and the control instrumentation. The intended behavior of the control systems is described in diagrams depicting the control logic. These diagrams are used as a basis for representation of decisions in the design process and are often used directly as templates for supervisory displays. Explicit information about relations between the means and ends of the physical process and the control systems can only be derived with difficulty from these diagrams and only with assistance from experts. Industry reuse design solutions in order to reduce engineering costs and the design rationale can therefore be difficult to acquire from the engineers and must therefore often be inferred from other sources of knowledge<sup>1</sup>.

There is accordingly a serious knowledge acquisition bottleneck in addition to the problem of translating information between different forms of representation. There is an interest in automation industry to improve the design process including the documentation but the risk involved in changing the design process is often too high.

Currently large efforts are made industry to develop system design standards. As an example can be mentioned the ISA standard S88 for design of batch control systems. These standards aim at reducing engineering costs and ensuring compatibility between systems solutions from different vendors. The design problems at the human machine interface are not considered and it is not clear how the work domain analysis of CSE relate to the models proposed in the standard.

Research studies in ecological interfaces based on the AH have been focused on a narrow range of control tasks and it is not clear to what extent the AH can cope with the diverse types of tasks involved in supervising complex industrial plant. They typically involve both continuous and discrete (e.g. batch) processes. Recent extensions of MFM include the possibility to represent a large variety of control tasks also comprising safety

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<sup>1</sup> A related problem appears in the field of systems biology where researchers try to understand the regulatory functions of microorganisms. Here there is no blueprint and information about regulatory functions (and thereby the purposes of the different processes involved) must be inferred. Recent research indicate that MFM may be used to model the biological processes on several levels of functional abstraction in order to obtain an overall understanding of the functional organization of microorganism (Gernaey, Lind and Jørgensen, 2004).

related controls (Lind, 2005). However, more work needs to be done in order to ensure sufficient coverage of MFM.

There is therefore little hope that means end concepts promoted by the CSE community will be accepted as a basis for integrated systems design unless these incompatibilities are reduced or completely eliminated.

### *13.2.2 The challenges of agent technology*

Current industrial interest in applying agent technology for process control and supervision may on a longer time scale contribute to a resolution of the incompatibility problem. Advanced types of software agents based on e.g. the BDI (belief, desire, intention) architecture are designed to deliberate about means and ends, to negotiate and to cooperate (Woolridge, 2000). This technology is claimed to be suitable for the implementation of self-configuring or self-organizing distributed control systems and is taken seriously in current developments in advanced controls for power networks and in holonic manufacturing systems. Successful application of agent technology will require confidence with means-end concepts and analysis by control systems designers and therefore possibly also change the control systems design process to facilitate integrated systems design as proposed by the CSE community. However, agent technology can and will therefore also be used to increase the level of automation and thereby to increase the complexity of the human supervisors task.

## **13.3 The problem of embedded controls**

One of the challenges of agent based control systems to CSE will be to be able to handle work domains with embedded control systems. This problem require an understanding of how the levels of functional abstraction are constituted and cuts therefore deeply into the foundations of means-end analysis (Lind, 2003 and 2004). An understanding of this modeling problem can only be obtained through formalization of means end concepts.

An aim of MFM research is to establish a formalized framework for means-end analysis and an understanding of the problem of embedded control is now emerging (Lind, 2005). One of the insights obtained from recent MFM work is that formalization (and thereby solution of the problem mentioned above) requires that model concepts should be adapted to the work domains (Lind, 2004). MFM is therefore now seen as a modeling language that is targeted towards a specific but still very comprehensive domain. This means that the set of flow functions in MFM is not generic but a set that is relevant for certain types of application. We cannot therefore support the idea of using the elementary flow functions to define generic building blocks for HMI design as proposed by Liu, Tanaka and Furuta (2002).

## **13.4 The needs for formalization**

The comparison of the AH and MFM made by Burns and Vicente (2001) seems also to miss the target. They suggest that the two modeling frameworks are different because MFM is goal oriented whereas the AH is structure oriented. The comparison seems to ignore the most significant difference which is in the levels of formalization of the two approaches to means-end analysis. The high level of formalization makes MFM suitable for solving the problem of embedded controls, for building reasoning systems for decision support and for validating the consistency of control systems design solutions whereas the low level of formalization of the AH makes it open to interpretation and

therefore unfit for the types of problem addressed by MFM. The AH may be easier to apply than MFM in less demanding informal design processes in industry.

#### *13.4.1 The Compatibility of MEA with Control theory*

Another obstacle towards bringing MEA into the control systems design process is the difficulty in connecting means-end analysis with concepts of mainstream control theory that, in the end, is the educational background of most control engineers. Within this tradition modeling the work domain would mean to define the differential equations that govern the behavior of the system. These models, which play a central role in the solution of control design problems, describe the dynamic dependencies between process variables representing mechanical and thermodynamic properties of both the material objects transformed in the process and the plant equipment. In contrast, means end analysis is anchored in common sense concepts of agency, actions and objects. In addition, concepts of intention and purpose play a central role in MEA whereas these notions, in spite of their obvious importance for understanding the concept of control, have no explicit representation in differential equations. This apparent incompatibility of the concepts of MEA and control theory makes it difficult to transfer knowledge about the ends and means of the automated controls to the HMI designers. They require this information in order to make the purposes and functions of the automated controls transparent to the operator. It is one of the future challenges for research in CSE (or control theory?) to develop an understanding of the relation between these two ways of conceptualizing and thereby modeling control phenomena. Recent preliminary studies by Lind (2004) has shown that means-end concepts play a crucial role in framing the modeling problem i.e. they are active in the so-called pre-scientific phase of problem setting. However, this knowledge is rarely documented and then only in an informal textual form. Formalized means-end analysis of the design control design problem would make this knowledge explicit. A deeper understanding of the relation would therefore be a valuable contribution to modeling methodology and would also enable an effective transfer of information between control engineers and HMI designers.

### **13.5 Using MEA to represent work domain constraints**

The present difficulties in linking MEA concepts firmly with concepts of control theory raise serious uncertainty concerning the validity of the second claim on our list – that means-end concepts can be used to represent the physical and intentional constraints of the work domain that are relevant for the operator's supervisory tasks. It is therefore thought-provoking that CSE researchers interested in ecological interfaces (Vicente, 1999) link their work to control theoretical modeling concepts (differential equations representing mass and energy balances) and at the same time argue for value of means-end concepts for representation of work domain constraints! This apparent contradiction could reflect a lack of consensus on MEA concepts in the CSE community.

#### *13.5.1 Independence on specific fault situations*

It is also claimed that means end concepts makes it possible to make representations of the work domain which are independent on specific fault situations. It is argued that means-end concepts produce models on a high level of functional abstraction describing normal behavior of the system under control. Fault situations would in such a representation appear as a deviation from the normal. Means-end models can therefore be used to diagnose unforeseen events. In this way means-end analysis in a neat way

circumvent the problem of approaches based on modeling fault behavior. Here it is necessary to consider all possible faults, a task which in most interesting cases will require much effort and the resulting fault models will suffer from completeness problems.

Here the problem is that we need to be more careful in defining what we mean by a situation. This means that the claim may be valid for certain types of upsets in the system so that the relations between levels of functional abstraction actually can be used to identify causes and consequences of a failed function as claimed. But what search paths should be followed in means-end space if assumptions that ensure the validity of the levels of functional abstraction are violated? In such situations it would probably be necessary to search for causes and consequences in the physical structure and the means-end analysis would not be of much value. A practical way of addressing this problem could be to combine means-end models with fault models in order to ensure coverage in such cases. Paulsen (2004) considered this possibility of combining results of risk analysis with MEA in display design. However, a more fundamental resolution of the problem would require an understanding of how levels of function are constituted in MEA. The same research challenge, which is created by the problem of embedded controls.

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**14. MANCINI, GIUSEPPE**

## 15. MCDONALD, NICK: MAPPING THE SOCIAL SPACE OF COMPLEX SYSTEMS

Decision making can be seen as one of a set of social processes through which organisations contact their operations. In order to understand how these social processes function normally, or to conceive how they could be improved, optimised or otherwise changed, it is necessary to develop as far as possible an understanding of their operational context – developing a rich picture, or thick description of the whole socio-technical situation. Such description needs to meet a number of requirements. It needs to be

- Grounded: addressing the normal operational activities of every day life, including informal and unofficial ways.
- Systemic: seen in the context of the organisational systems and processes which constrain and influence activity – a functional model.
- Dynamic: Concerned with activity over time and processes of stability and change.
- Meaningful: Encompassing the way in which people make sense of understand their activity in its systemic context.

The Knowledge Space Model (KSM) is a broad methodological approach which seeks to fulfil all these requirements in understanding the human role in complex systems. It has been developed in the context of the design of new technologies and processes for aircraft maintenance. However the principles can be adapted to other operational situations and a variety of social processes.

It is based on the following principles:-

Mapping the relevant operational processes - this gives the functional requirements and operational sequence of that process. Such process maps represent a sequence of stages rather than an account of all the activities that energise such processes.

Gathering accounts of actual occurrences around these processes. Narratives can come from different sources (events, audits, anecdotes, other analyses). Such narratives preserve the sequence of activity, they allow interpretation of intentionality and causality, they structure the activity in terms of the actors, the context and the outcomes, and enable an ongoing evaluation of this activity as well as drawing conclusions

Designing prototypical narratives, which are general accounts of what typically happens around the operational processes.

Mapping social processes. All evidence is used to construct a systematic model of the social processes which underlie the normative patterns of activity included in the narratives (these are not just at the 'sharp-end' but extend across the whole process space). These accounts can be constructed at different levels.

Devising requirements to optimise process functioning, for example, information requirements or competence requirements.

Devising requirements for future systems. This methodology is currently being developed. Ingredients of this activity include the capturing of tacit knowledge in

narratives as well as the active participation of relevant technical /operational experience in 'knowledge transformation workshops'.

This approach stands in contrast to conventional HF approaches to operational systems, in which human activity is presented in an atomised, de-contextualised manner, and in which Human Factors is rarely more than an evaluation activity for already-produced new systems. It also challenges social-constructionist accounts of organisational functioning, which do not adequately address the social-technical nexus and the possibilities of change. The KSM methodology is intended to support the development of future systems which more clearly meet human operational requirements and to provide a more precise understanding of the requirements for organisational and process change.

## 16. MAY, MICHAEL: ABSTRACTION AND REPRESENTATION

### 16.1 Outline of the argument

Since this is an extended position statement and not a finished paper, I will briefly outline the basic argument as it fits in with the reunion/workshop on Intelligent decision support in process environments.

The position paper attempts to present a systematic and analytical approach to the multimedia multimodal design space of interfaces in the context of support for tailoring in supervisory control. The approach is based on logical semiotics (i.e. the theory of signs and signification originating with C.S. Peirce), on modern cognitive semantics (G. Lakoff, L. Talmy, G. Fauconnier, P. Gärdenfors a.o.) and on the theory of scales of measurement (originating with S.S. Stevens) and a revision of its use within the theory of distributed representations (J. Zhang, D. Norman, E. Hutchins). The approach includes a feature-based taxonomy of media and representational forms and in this part the theory is also based on Formal Concept Analysis (FCA) (May, to appear). The whole approach should be seen in the context of joint work on the conceptual foundations of human-machine interaction in supervisory control (including the further development of MFM) being carried out with Johannes Petersen and Morten Lind at Ørsted, DTU.

The link back to the workshop at San Miniato (IDSS 1985) is the following. We claim that it could be beneficial for the further development of the paradigm of Cognitive Systems Engineering (CSE) to go back to its foundation in the 1980-ies (Rasmussen & Lind 1981; Norman 1982; Woods & Hollnagel 1983, Norman 1986; Woods & Roth 1988) in order to reconsider the foundation from present theoretical accounts (of distribution, scaling, property spaces, formal concepts, cognitive support etc.) and track the changes that occurred with the introduction of the “ecological” paradigm, i.e. the turn towards Ecological Interface Design (EID). Although this “Gibsonian turn” of CSE in many ways represents an important contribution to CSE, it also involved a narrowing down of its scope (at least in the way this paradigm have been interpreted in later practice) – and the approach to interface and “representation design” is an example of this. Similarly we should go behind the foundation of EID (Vicente & Rasmussen 1990, Vicente & Rasmussen 1992) and reconsider its foundation (for instance in the concept of “affordances”, which does not originate with Gibson but with the “topological psychology” of Kurt Lewin in the 1940-ies).

The point of going back to the sources of the CSE and EID is, among other things, to make the implicit semiotic assumptions explicit so that they can be evaluated and restated in a coherent form. This “implicit semiotics” can be found in many core writings within the CSE paradigm (Rasmussen & Lind 1981; Rasmussen 1983; Woods & Roth 1988) in the form of assumptions about “signs”, “signals”, “representations”, “descriptive” versus “depictive” representational forms etc. The attempt to articulate CSE, and more specifically the multilevel flow models (MFM) in the context of process control, with an explicit semantic and semiotic structure has primarily been undertaken by the Automation group at Ørsted-DTU (Lind 1999a, Petersen 2000; Lind 2001; Lind 2003).

## 16.2 The “gulf of design” in constraining the design space

Direct manipulation interfaces (originally proposed by Sneiderman) have been seen as a solution to the “gulf of execution” problem (Norman 1986), and Ecological Interface Design (EID) (Rasmussen & Vicente) have been seen as a further specification of this solution for complex work domains. There is however still a “gulf of design” in bridging domain abstractions and interface representations. The gulf of design is the problem of how to constrain the design space of multimedia multimodal interface components in supporting complex work activities through adaptation and/or tailoring.

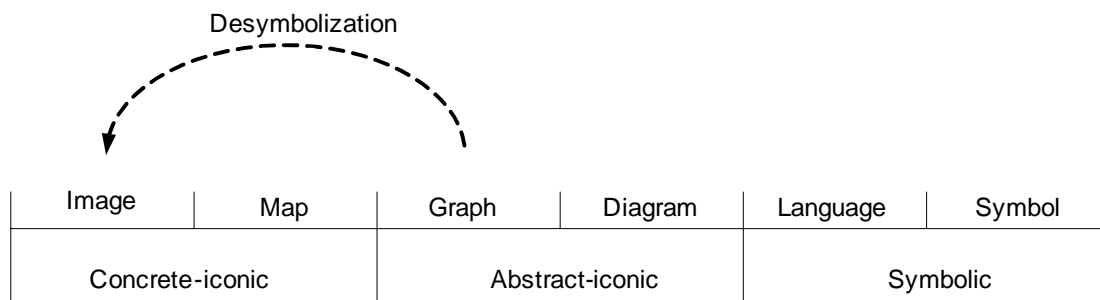
The idea of “direct perception” of affordances does not help designers in deciding on the form of representation (in the sense explained below) for particular types of information that needs to be exchanged through the interface of a Human-Machine System. EID claims to have solved this problem, at least partially, but it only appears to be the case because EID focuses on particular types of information content, i.e. constraints, and particular choices of expression of this content (graphs and “configural” displays) based on information integration. Although they are important, graphs and “configural” displays are only a part of the design space relevant for Human-Machine Systems.

A systematic understanding of the design space is necessary in designing for safety in complex work domains, whether the strategy of design is to develop “smart” adaptive interfaces or to support tailoring by the operators in unforeseen situations (Petersen & May, to appear).

## 16.3 The example of “configural displays”

Configural displays (mapping several variables to an integrated geometric form) have been found to be more effective in supporting tasks than pure symbolic “digital displays”, but “composite displays” using multiple forms of representation was found to be even more effective (Bennett & Walters 2001). In fact the authors warn against concluding that configural displays are somehow optimal designs, and points out that the “coding conventions associated with each individual variable” must be considered since these need to be related unambiguously to represented system states. It is not enough that information can be obtained easily from the graphics, it “must also be semantically meaningful in the context of the domain task(s) to be performed” (Bennett & Walters 2001).

There is a semantic problem in discussing “configural displays” in that some of these displays for representing multivariate data are in fact graphs with an unambiguous relation to represented system states (for example the Carnot cycles and Rankine cycles used in thermodynamics, or the Smith charts used in electrical engineering), whereas others (like Chernoff faces or the “time tunnels” suggested at RISØ) tend to be “desymbolized” as images, i.e. their interpretation will tend to rely only on properties of images (like shape, size etc.) rather than on the relational properties of graphs. The two representational forms are not clearly distinguish by EID as seen in the following description of configural displays: “The shape may be a commonly familiar shape, such as in the polygon graphics, or it may be a shape that is meaningful to the particular process, as in the rankine cycle graphic.” (Burns & Hajdukiewicz 2004, p. 68). Below a figure to illustrate the process of desymbolization as a transformation of representational form (“sign type”) (May, to appear).



The criticism here is not directed at configural displays as such, but at the potential confusion of image-based and graph-based properties. In many cases they have proved to be efficient in supporting complex monitoring tasks, and there are for instance many applications of Rankine-like graphs in domains as diverse as anaesthesia and nuclear power plant control.

#### 16.4 The danger of reductionism inherent in EID

There is a tendency in EID towards conceptual reduction of representation in at least two different ways. This inherent danger of disregarding representational issues is of course paradoxical since EID deals with “representation design”, but never the less it can be seen clearly in discussions of the relation of EID to ecological psychology (Vicente & Rasmussen 1990).

(1) There is a tendency toward a reduction of the semantic choice of representational forms to the problem of “conveying affordances” of the domain making them available through “direct perception” (and with the exception of Sanderson work on the extension of EID to auditory displays, this is furthermore taken to mean direct visual perception of graphical forms, i.e. excluding acoustic, gestic and haptic media for presentation of information).

This implies a kind of semantic collapse of the design space on the physical description of constraints in the domain, since the task of “conveying affordances” by the designer is seen as “inverse ecological optics” (sic!) (Vicente & Rasmussen 1990). This reduction can go relatively unnoticed because of a kind of default assumption in EID (“In general, EID would advocate the use of a configural display” ... to support higher-order properties etc., as described by Reising & Sanderson 2002), but at the same time it is reported that higher-order properties could in fact be represented effectively in other ways (cf. the example of the bar graphs discussed by Ham & Yoon 2001).

From the point of view presented in this position statement there are in fact two dimensions involved at the expression level of the design space: the cognitive and semantic properties of representational forms (image, map, graph, diagram, language, symbol) and the added properties of the physical media (graphical, acoustic, gestic, haptic) in which these forms are expressed. In semiotics the abstract representational forms are sometimes called “sign types” or “forms of expression”, whereas their physical realisation (“presentation”) in a media is called the “substance of expression”. Neither form nor substance of expression should be confused with the specific communicated content (see overview diagram at the end of this position paper) or with the spatial and temporal layout.

(2) There is a tendency toward a reduction of the syntactic choice of spatio-temporal layout to the problem of expressing “the relational structure of the domain” (i.e. constraints), since it is claimed that “organizing the information in the interface” is directly “equivalent to” (sic!) determining the relations between affordances of the domain (Vicente & Rasmussen 1990). The ideal is so to speak that the domain could “speak for itself”, without any need for a genuine (semiotic) articulation of the information content in the interface or any further (aesthetic and cognitive ergonomic) layout considerations.

The separation of expression as well as content from spatial and temporal layout is considered an important progress in interface design within multimedia design and information presentation (Bateman, J., Kamps T., Kleinz, J., & Reichenberger, K. (2001); Purchase & Naumann 2001; May, to appear), and it should not be ignored in the context of human-machine interaction and Cognitive Systems Engineering. In fact the foundational paper on EID and ecological psychology (Vicente & Rasmussen 1990) argues for an analysis of “smart instruments” which should address questions about form, content and structure, but unfortunately the content is only understood in terms of domain content (measured properties) and not in terms of semantic content (of the representation), structure is only understood in terms of relations in the domain (constraints) and not in terms of “interfaces structures”, and form is only considered as the visual forms supporting “direct perception” (the configural displays). A general understanding of the relation between interfaces and domains, such as the relation between interface representations and domain abstractions, is thus excluded from EID because of the conceptual reduction in what is considered as “form, content and structure”.

### **16.5 The “language of interface design”**

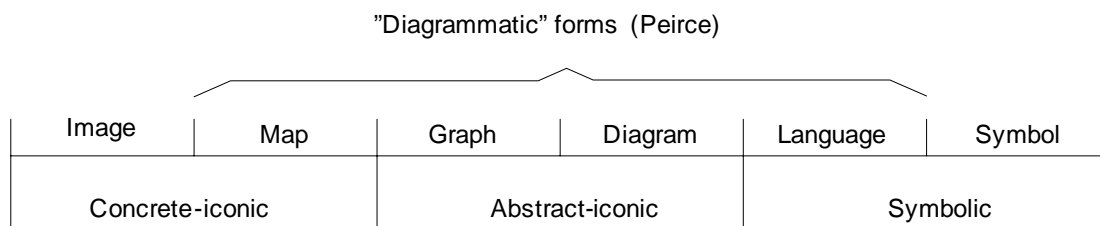
Methodologically EID will usually introduce design solutions based on a Work Domain Analysis (WDA) and the principle of presenting constraints in the domain for direct perception and manipulation. Sometimes the design solution is backed up by empirical evidence indicating that it is more efficient than an existing solution. This procedure does however not exclude that there could be a whole range of other design solutions that would support operators equally well or even better; the point being that the design solutions of EID does not rest on an analytical understanding of the design space as a whole.

Furthermore the methodology of WDA is insufficient for deciding on relevant interface components, since it does not include a task analysis. A recent example is the sketch for a hypothetical car interface generated by (Burns & Hajdukiewicz 2004) to illustrate the use of WDA in design. Besides suggestions for relevant displays based on multivariate constraints (such as a display to show the remaining “fuel range” in km) they suggest presenting graphs of energy-related engine information to drivers (fuel injection rate, engine pressure as a function of engine temperature, and exhaust temperature), although these displays would certainly be irrelevant for ordinary drivers (not trained in engine diagnostics). At the same time other relevant displays that could have been suggested from an EID point of view are not generated (an example could be a display of variable stopping distance).

Since (Burns & Hajdukiewicz 2004) does in fact present a “language of interface design” it is possible to evaluate the limitations of their EID-based conception of the

design space. For some reason they start out by implicitly excluding acoustic, gestic as well as haptic media (display & input) components and only analyze graphic display components, although they later refer to the work of (Sanderson et.al. 2000) as an extension of EID to include auditory displays and sonification of information. Following an early paper by David Woods on representation design they actually refer to semiotics with regard to the overall distinction between “propositional” (i.e. language), “iconic” (in the narrow HCI-sense of images and graphic symbols) and “analogical” forms (where they consider maps and graphs, but disregard the important category of diagrams) of representation and communication.

They do however not consider the semiotic distinction between iconic and symbolic in its full form (originating with the logical semiotics of C.S. Peirce), where we find a whole range of representational forms between the image (the most “concrete” iconic form) and the condensed symbol (the most “abstract” symbolic form). Another important aspect of the relation between signs and the “objects” they represent (“the represented world” in the terminology of Palmer 1978) is the indexical relation, which relate signs causally to their objects (which means that indexicality will always be involved in signs of higher-order properties derived from basic measurements). Below is a schematic diagram of the fundamental representational forms with a coarse distinction between three forms (Purchase & Naumann 2001) and a more fine grained distinction between six forms (May, to appear).



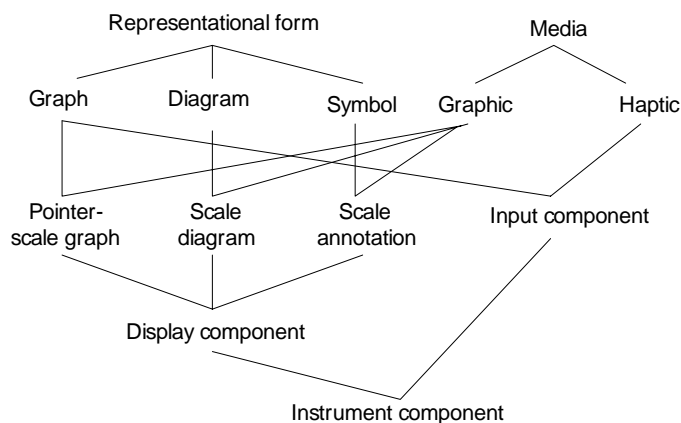
### Media types, scale types and representational forms

As implied above the semiotic theory suggested here, as an extension of the CSE paradigm, involves a conceptual distinction between the representational expression, the communicated content and the spatio-temporal structure (“interface structures”) of the “representing world” on one hand, and a domain content of the “represented world” on the other hand.

In this respect there is already a CSE triangle implied in the purely representational problem of the relations between sign (expression as well as content) and world (domain content as the reference of the sign). Beyond representation and world (cf. the CSE triangle of Woods & Roth 1988), the agents and their situated and distributed activity make up a more complicated setting for CSE. In the present paper the focus is only on the representational issues.

The “sign unit” in the present context is any type of interface component. Interface components will often have a dual side: one side will display information to an operator and another side will make some control actions available (as an affordance in EID terminology). Although we have specialised “input devices” and “interfaces” (in the restricted sense of display technologies) the general concept of an interface component of human-machine interaction will have a display as well as a control aspect.

A nice example is the traditional engine telegraph on the ship bridge. The traditional electromechanical engine telegraph permits a (“remote”) control action to be performed with regard to ship propulsion by communicating a desired speed category (like “Full Astern”) to the engine control room, but it also displays information about the desired speed to agents on the bridge (the position of the handle is visible from any location on the bridge, and one engine telegraph can be reduced to a repeater device of another engine telegraph, i.e. forced to follow the movement of the engine telegraph “in command”). The desired speed is both controlled and displayed along two different scales, i.e. on an ordinal scale (stop < slow < half < full speed) and on a nominal scale indicating direction (astern, [neutral], ahead), and these two scales are combined (corresponding to the combination of two types of information: speed category information and directional information). As an input device for control actions it is a haptic media component permitting 1-dimensional manual input on the specified scales for ordinal speed and nominal direction. As a display component it is a visually perceived graphical media component (and temporally it supports sequential manipulation / animation).



Two different media is thus utilised by the component (haptic and graphic) as its media of manipulation and media of expression respectively, but it also involves three representational forms. The display component is basically a graph supported by a schematic structure that we could call a scale diagram to make the two aligned scales explicit and by symbols (as scale annotation). The engine telegraph is a graph in its representational role as a display component and also in its representational role as an input component (input device). We could reformulate these interconnected representations by stating that the graph has a descriptive role (as a display of information) and a prescriptive role (as an input device for control actions). From a formal point of view the electromechanical device is similar to an interface component like the slide bar (which is also a graph presented graphically, although it needs a separate input device for manipulation), but they are different from a human factors point of view: a “soft instrument” component does not embody all the affordances and display qualities of the electromechanical device.

In the general case interface components in HCI and HMI should be conceptualised as multimedia units, cf. also (Nesbitt 2001). There is no special reason why we should not allow interface components to utilize several media (graphic, acoustic, gestic, haptic) at the same time and we should also be prepared to conceptualise them as being

“multimodal” with regard to representational forms or “sign types” (combining image, map, graph, diagram, language and symbol types).

In fact the prototypical artefacts that we are familiar with (like the engine telegraph on a ship, the interactive metro map in a subway station, or the enunciator alarm panel in a control room) are almost always multimedia multimodal artefacts combining different media of manipulation and presentation for the expression of multiple forms of representation.

Even though we often think about the familiar (“pseudo-concrete”) objects as simple, they are in fact conceptually complex objects combining many semantic properties inherited from abstract representational forms and “emergent properties” are added by the media of manipulation and expression. That is why traditional classification schemes for graphical design and multimedia design have been inconsistent as well as incomplete (May, to appear).

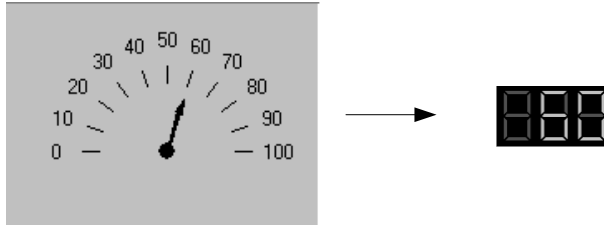
A graph expressed in the graphical media (what we usually associate with graphs) have some core semantic properties common to all graphs and then some additional “emergent” properties that derives from its expression in the graphical media. A graph expressed in the acoustic media (an “auditory graph”) has the same core semantic properties, but have other “emergent” properties derived from the acoustic media. A diagram expressed in graphics have core properties that are different from those of graphs, but they are the same core properties that diagram in the haptic media have (“tactile diagrams”). The difference between graphs and diagrams as representational forms is constituted by the semantic core properties which are invariant across transformations of media (Stenning, Inder, & Neilson 1995; May, to appear).

In this way we can set up a consistent taxonomy of simple types of interface components through the free combination of feature structures describing the properties of media (graphic, acoustic, gestic, haptic) and the properties of representational forms (image, map, graph, diagram, language, symbol on a first level of specification). A brief sketch of how this can be done is shown in the next section on the formal structure of the design space.

The kind of design space which emerges from this construction also supports the formation of complex components from simple components and it is therefore very well suited to analytically describe the complex but familiar (“prototypical”) interface components as well as the unfamiliar but possible components that have not yet been designed or fully explored. One can, in other words, use the design space as an exploratory tool to investigate and understand interface components and their semantic properties. The real strength however of this conceptualization is the potential for describing the design space of media and representational forms fully integrated with the scale types and scale transformations needed for flexible information presentation and support for tailoring.

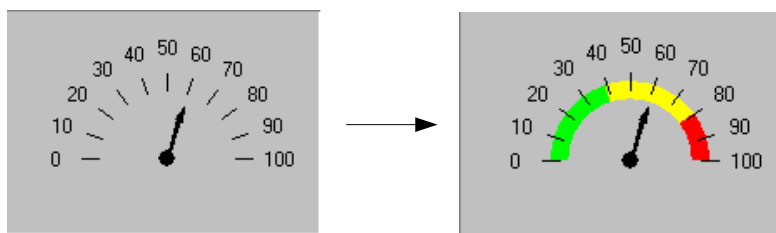
A few examples using traditional gauges and graph displays can clarify the proposed conception of the design space before we turn to a sketch of its formal structure. Below to the left some reading is given on a traditional “analogue” dial instrument display (for the purpose of the example we do not discuss the domain content here, i.e. what the measurement is about). A transformation of this instrument is shown (it could occur at “design time” or at “run time” through tailoring) turning it into a “digital” display. In

both cases the measurement data is given on (we assume) a ratio scale and it is presented on a ratio scale as well, so the mapping from measurement data to the presentation of this data preserves the scale type (cf. Zhang 1996; Petersen & May, to appear).

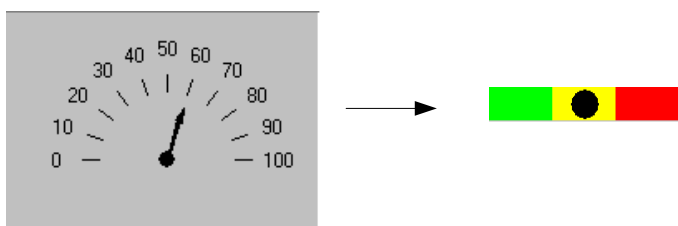


The scale type itself (ratio scale) is not changed by the transformation shown (here we are in disagreement with the analysis of J. Zhang), but the explicit graphical representation of it (showing min at “0” and max at “100”) is changed by the transformation, since it is implicit in the digital display. The representational form however is changed radically however, since the “analogue” dial instrument is basically a graph (the pointer-dial component is an animated graph, although its explicit graphical scale has to be annotated by symbols), whereas the “propositional” digital display uses numerical symbols (as a form of expression they are interpreted on a ratio scale although their substance of expression are graphical forms, i.e. image-like shapes, which is the level at which Zhang describes numerical symbols).

Another example is shown below. Here the dial instrument display is preserved by the transformation, but a second graphical scale, of an ordinal scale type (displayed through colour coding of three areas), have been superimposed on the first graphical scale. This illustrates superimposition of graphical scales, which can be very relevant for redesign and tailoring (Petersen & May, to appear).



A third example shows a transformation of representational form that also involves a change in scale type. In stead of superimposing the ordinal scale, we could substitute the ratio scale of the dial instrument with a presentation on an ordinal scale. This scale substitution will change the layout of the pointer-dial component: the operator will now only see the pointer in a cell position and not as pointing to an exact numerical value, but his reduction could in fact have a higher information value for the operator under some circumstances, where the exact value is irrelevant.

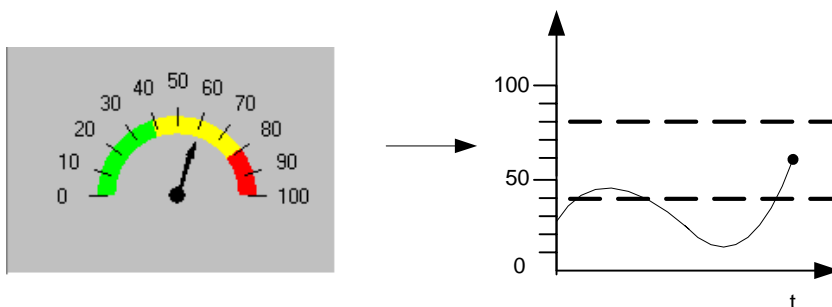


A further reduction to a “weaker” scale (see Petersen & May, to appear) is possible based on a transformation of the ordinal scale to a nominal scale, where the measured variable is simply classified as being “OK” (within the desired range) or not. Here the ordinal information is lost in the presentation (this corresponds to a simple alarm).

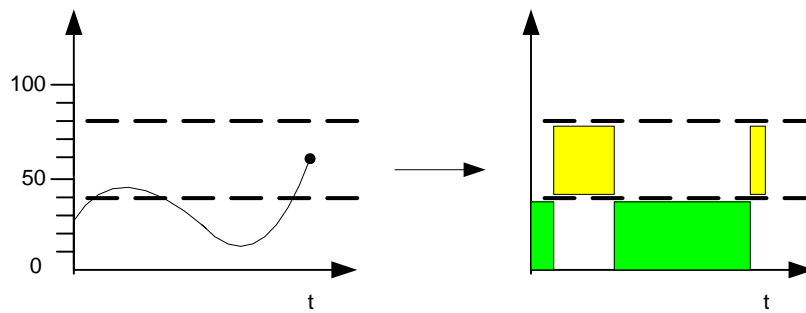


An alternative to the indicator light on the nominal scale shown above would of course be having an auditory alarm triggered, when the measured variable is passing beyond the desired range. In the design space this would correspond to a transformation in the media type from graphical to acoustic media presentations. The graphical indicator light and the auditory alarm would however both be on the same scale (nominal scale) and both have the same representational form (symbol). We could however also change the representational form of the alarm – for instance if we wanted to have a spoken warning or alarm, in which case the representational form is transformed from symbol to language.

A final example can illustrate a transformation within a representational form between subtypes. Below to the left is shown the dial instrument display with the ratio scale and a superimposed ordinal scale. In the pointer-scale component the temporal dimension of the graph is implicit, which means that the operator – if knowledge of the history of the measured variable is important for the task – has to construct and remember this history. This will of course impose an added workload on the supervisory control tasks. A transformation within the graph category from the pointer-scale component to a history graph will make the temporal dimension explicit by adding the dimension of time. The superimposed ordinal scale will here be shown as reference lines for the graph on the axis of measured values.



As in the case with the dial instrument display we could also have a scale substitution within the history graph resulting in the transformation of the history graph to the left to the ordinal history graph on the right, where exact measurements on a ratio scale is lost in the presentation. Instead there is a focus on “time blocks” within the different ordinal regions that might give important information to the operator.



The theory of scale types (ratio, interval, ordinal and nominal) and distributed representations is introduced in (Zhang 1996) and the theory of scale transformations as support for tailoring is introduced in (Petersen & May, to appear). The different types of transformations and operations illustrated (such as substitution and superimposition of scale, transformation of media type, and transformation of representational form) can all be “pasted together” in a lattice-like design space, which could also account for the constructive composition of complex interface components (as shown for the engine telegraph example, but without the scale specifications).

The resulting (very large) lattice of specifications (upward join in the lattice) and combinations (downward meet in the lattice) will give a phenomenological description of the complete design space of multimedia multimodal interface components, as opposed to an analytical description of the properties of these components. The analytical description is what I would call the formal structure of the design space.

### 16.6 The formal structure of the design space

The taxonomy of the media and representational forms suggested here was sketched in part in (May 2001a; May 2001b; May & Andersen 2001; May, to appear). It relies on a set of fundamental principles:

- There are a limited number of media types derived from sensory modalities and forms of communication relevant for computer-based interaction (i.e. graphic, acoustic, gestic, and haptic)
- There are a limited number of possible un-combined representational forms (“sign types”)
- It is possible to give a feature-based description of their semantic properties
- Some of these properties are invariant across media types whereas other properties and operational possibilities are emergent with the expression of signs within a media
- Invariant properties (the “core” semantics) are inherited to syntactic combinations of representational forms whereas their emergent properties are constrained by the specific combinations of media types and representational forms

From a formal point of view the feature structure approach to the classification of properties correspond to setting up a lattice of the logical combinations of features. This approach to taxonomy of conceptual structures has been formalised in Formal Concept

Analysis (Ganter & Wille 1999), where features (“attributes”) and the concepts they specify (the “objects”) are related in a matrix called a formal context.

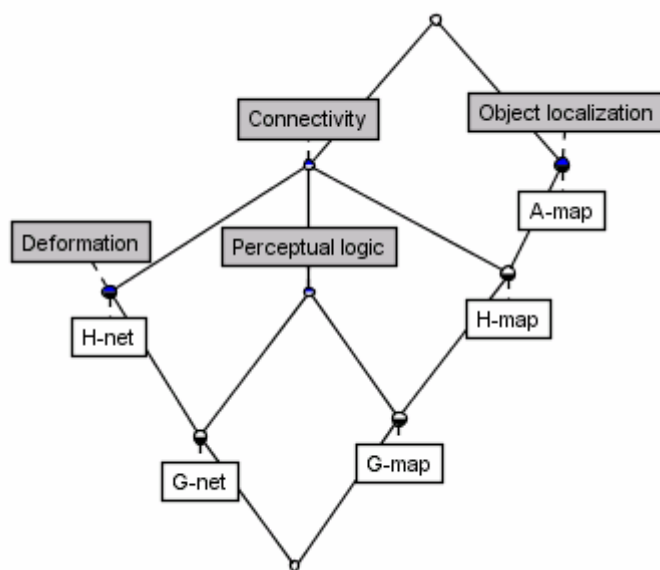
A formal context  $C := (G, M, I)$  is defined as two sets  $G$  (from German “Gegenstände”, Objects) and  $M$  (from German “Merkmale”, attributes) with a relation  $I$  between  $G$  and  $M$ . The elements of  $G$  are the objects and the elements of  $M$  are the attributes or features of the context. From the formal context all possible combinations of formal concepts can be generated. A formal concept is a pair  $(a, b)$  where  $a$  belongs to the set of objects  $G$  and  $b$  belongs to the set of attributes  $M$ . To construct a lattice we have to add two points: the “top” element corresponding to the empty set of objects and the union of all attributes and the “bottom” element corresponding to the full list of objects and the empty set of attributes.

Consider maps and network charts (a particular type of diagram) as two different representational forms. We can express what this difference means, in terms of the semantic features and supported operations associated with each form within different media, by setting up the formal context for these simple objects. The following example is just given as a sketch of what such an analysis could look like and the simplified formal context only includes the following five objects and four attributes (semantic features and supported operations). The attributes of the example are:

- Connectivity: does the type require connectivity to be preserved?
- Perceptual logic: does the type support “direct perception” of logical relations in a spatial structure?
- Deformation: does the type support (and allow) deformation?
- Object localization: does the type support localization of objects relative to a “background” reference object (not just localization of parts within a whole)?

	Connectivity	Perceptual logic	Deformation	Object localization
Graphical map (G-map)	+	+		+
Haptic map (H-map)	+			+
Acoustic map (A-map)				+
Graphical net (G-net)	+	+	+	
Haptic net (H-net)	+		+	

Table indicating a small part of a formal context specifying the map and the network chart types expressed in different media.



A Hasse-diagram of the lattice corresponding to the formal concepts specifying maps and network charts according to the (simplified) formal context sketched above.

It is implied by this analysis that the familiar graphical maps – although they are prototypical maps – do not exemplify the core semantics of maps. It is in fact the apparently peripheral case of the acoustic map (A-map) that exemplifies the core semantics of maps, because it is the attributes of acoustic maps (in the example here reduced to the feature “Object localization”) that is shared by all maps. Graphical maps, of course, also have this feature, but in addition they have other emergent features derived from the graphical media (Connectivity and Perceptual logic).

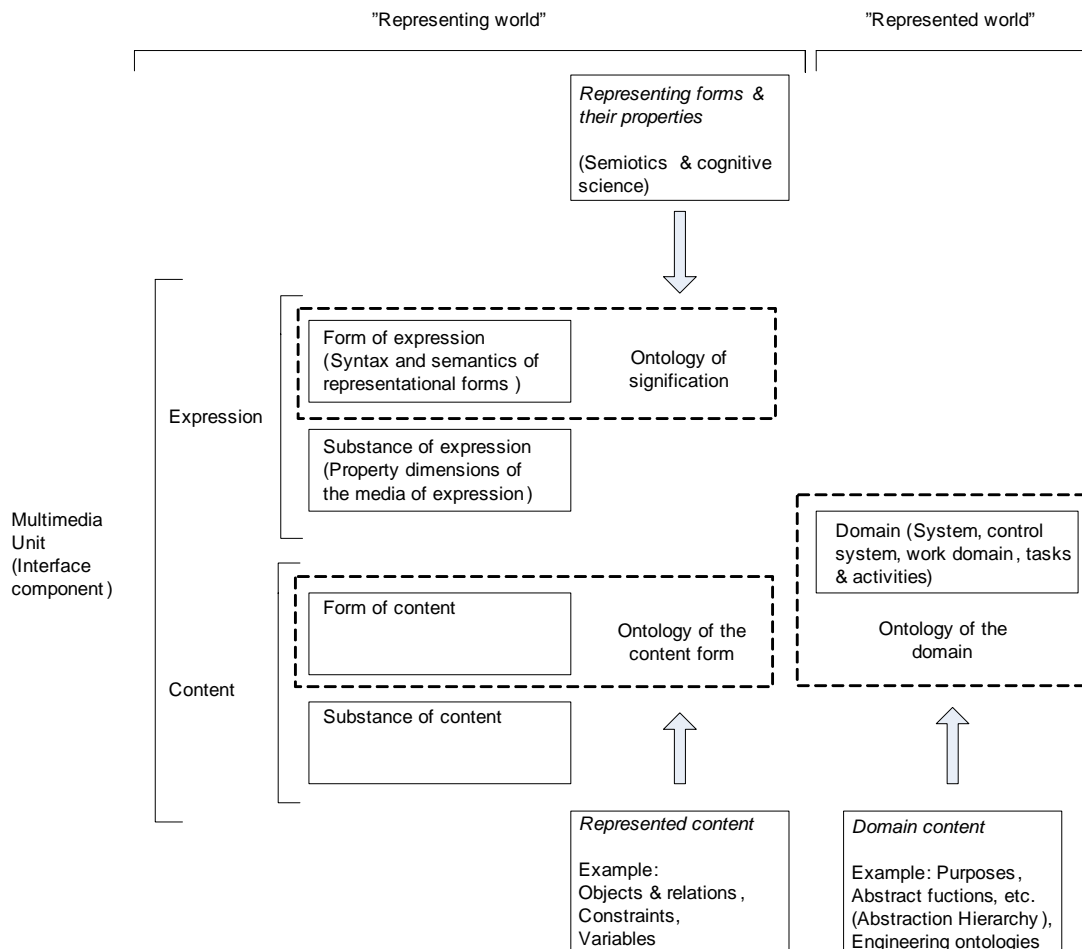
### 16.7 Preliminary conclusion

Since this is intended as a discussion paper there is no conclusion at this point, but the work in progress presented here should be understood in the context of joint work with Johannes Petersen and Morten Lind (see also their position papers for IDSS 2005).

Important further stages of the work in progress (the part of it presented here) will be:

- Description of the core semantics of representational forms in terms of their semantic and cognitive properties.
- Concept exploration of the lattice describing the design space.
- Articulation of the scale theory within the concept lattice describing the design space (this is known as “scaling” within Formal Concept Analysis).
- Analysing the specific cognitive support provided by different choices of media and representational forms for the expression of different types of data (whether measured or derived)
- Relating the semiotic description of the design space with the reconstruction of CSE and MFM. One key to this is to understand the description of media types and representational forms as providing an ontology of signification. Within such a framework the “abstraction hierarchy” should be understood as abstractions over

domain content (Petersen 2004a) corresponding to an engineering ontology (among other possible engineering ontologies for different domains). The “three layer model” distinguishing variables, constraints and objects & relations (Petersen 2004a) is to be understood as providing an ontology for the content form of interface components (see Johannes Petersens position statement).



The schematic diagram above gives an overview of important representational issues within CSE (not CSE, EID or WDA as a whole) based on the semiotic distinction (going back to Hjelmslev) between Expression and Content and within each of these between Form and Substance. The sign triangle (Peirce's sign, interpretant and object) in this model can be seen as relating a physical expression, a (representational) content and a domain content.

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## **17. MILLER, ANNE: TEMPORALITY: THE FORGOTTEN DRIVER IN HUMAN-SYSTEMS INTERACTIONS**

We get up in the morning; we go about social and productive activities interrupted by the need or desire for food, and at some point we go to bed and begin the cycle again. The temporal organisation of human activity is not limited to daily rhythms but extends to weekly and annual patterns (Zerubavel, 1979). Daily and annual patterns are typically thought to have an ecological basis; they represent a connection between human activity and events occurring in the environment; the effects of the Earth's rotation (daily pattern) and its orbit around the Sun (seasonal patterns). Pre-industrial human activity and society adapted to temporality in the natural environment, but survival and prosperity was vicarious.

Industrial production methods have insulated human activity from environmental uncertainties (Zuboff, 1984). Over time the relative isolation of work from the natural environment has shaped the way we as researchers, designers and analysts conceptualise socio-technical industrial systems. Our generic conceptualisations of socio-technical systems are reflected in the dimensions we include in analytical frameworks such as Work Domain Analysis (Rasmussen et al 1994; Vicente, 1999). The Work Domain Analysis framework for example includes two conceptual dimensions: a whole-part dimension that describes a system in terms of structural relations between wholes and parts and an abstract dimension that describes a system in terms of functional relations. In combination these dimensions describe a socio-technical system according to 'why, what, how' relationships. Temporal or 'when' relations are not included in these types of system models or descriptions

Over the last 30 years, enterprises including utilities such as power production enterprises (Memisevic et al, 2005) have become relatively more open to environmental, social and economic influences which like natural phenomena have different levels of periodicity i.e. daily, weekly, annual periodic cycles (Zerubavel, 1979). Current frameworks for modelling complex socio-technical systems do not accommodate temporal dynamics or periodicities, nor do we have coherent theoretical explanations about human behaviour in response to temporal dynamics, despite that temporality is an inherent part of our biological and social make up.

Healthcare has always been a substantially open system. The reason for a hospital's existence is to provide care to patients as and when patients need it. Hence the operations and the services a hospital provides are very much driven by the population profile (age, incidence and prevalence of illness) of people in its catchment area. The relative incidences of illnesses that present to hospitals have probabilistic temporal dimensions. For example, in a particular area more chest infections may present in autumn-winter and more near-drowning and spinal injuries may present in summer; trauma from motor vehicle accidents is higher on Friday and Saturday nights than on Monday and Tuesday nights and more likely to occur between 6 pm and mid-night than between 6 am and mid-day. We know very little about how staff apprehend these patterns or how they organise their work collectively and individually to accommodate temporal variation.

As more enterprises become open to environmental variability we will need to move towards a more socio-technical-information systems approach that accommodates temporality characteristic of open systems.

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## 18. MORAY, NEVILLE: THINKING ABOUT HELPING DECISIONS

If we are interested in the design of “decision aids”, it may help to think about the different ways in which people make decisions. Perhaps a table may help.

### 18.1 What can an aid do?

		Information available		
		Complete complex information	Partial Information	Perceptual
Action available	Many complex options	Help to remember possibilities, what info is relevant or available, and what actions are available. Help with weightings. Suggest “best” option.	Make sure all available info is used, and remind about what is not available. Help with weightings  Suggest “best” option	Provide “ecological display” to allow direct perception of location in state space, and relevant actions to state
	A few options	Make sure all are presented and weightings are appropriate	Suggest extra info, warn about missing alternatives both for info and action	Show as patterns
	Simple choice	Map complex info onto few possible actions	Map info onto actions	Enhance signal to noise ratio and “optimize” probability and payoff biases.

As we move toward the top left, the role of decision aiding is to support the use of the maximum amount of information and the maximum number of action options. As we move down to the right the role of decision aiding is to enhance the detectability and identification of the signals and to help mapping to output, in both cases using signal detection theory as a paradigm.

Some other thoughts. As we move to the top left we are more likely to be in the classical decision theory area, where we are trying to optimize or satisfice on the basis of enumeration of possibilities, followed by deductive thought to choose the “best” or the local best (satisficing). As we move down to the right we are moving towards recognition based decisions where the identification of some pattern is what is important, together with an action mapped to that pattern on one-to-one.

If top left is deductive thought, then bottom right is “intuitive”, “habit”, and “strength of belief”, not reasoning. If we want a model for strength of belief then Evidence Theory may be appropriate. We may know something is objectively not very probable but be absolutely convinced it is going to happen.

If we are designing decision aids for the top left, we are concerned to help with deductive reasoning, identification of options, weighting, etc. If we are designing for the bottom right, decision aids should enhance SN ratios, filter noise, support unconscious estimates of probability and payoffs., etc.

There was once a project performed by Perceptronix Inc to aid decision making under pressure in which pilot's decisions were recorded, and then on subsequent occasions he was told, "last time you made this decision you decided X". What do you think that was supporting?

## **19. NAIKAR, NEELAM: ENHANCING DECISION EFFECTIVENESS WITH COGNITIVE WORK ANALYSIS: THEORETICAL AND METHODOLOGICAL DEVELOPMENTS IN WORK DOMAIN ANALYSIS**

In the 1985 Proceedings of the NATO Advanced Study Institute on Intelligent Decision Support in Process Environments, Jens Rasmussen argued for the importance of designing decision support systems that are not only effective during stable, routine conditions but also during situations that have not been foreseen by designers or that are not familiar to professional, trained workers. He argued that in order to develop such systems, design cannot be based on detailed, quantitative, or normative prescriptions of task processes or sequences but instead should be based on a model or a framework that defines the boundaries of a design envelope within which workers can generate ad hoc practices that not only suit their subjective preferences but also the particular demands of the situations or contingencies at hand. His paper at the 1985 workshop focussed on describing such a framework; a framework which is now popularly known as cognitive work analysis.

Since the 1985 workshop, cognitive work analysis has been gaining increasing attention as a promising approach for the analysis, design, and evaluation of complex sociotechnical systems. Researchers have explored the use of cognitive work analysis for: designing teams, interfaces, and other decision support systems, evaluating design proposals, identifying training needs, and developing specifications (e.g., Burns, 2000; Dinadis & Vicente, 1999; Gualtieri, Elm, Potter & Roth, 2001; Linegang & Lintern, 2003; Rasmussen, 1998; Vicente, 1992a,b; Naikar, Pearce, Drumm & Sanderson, 2003; Naikar & Sanderson, 1999, 2001). Moreover, in the last 20 years, cognitive work analysis has been researched and practiced by many more analysts than the members of the original team who developed this framework at the RISO National Laboratory.

One interesting and, as yet, largely unacknowledged consequence of the gaining popularity of cognitive work analysis has been the evolution of divergences in the theoretical approaches and methodological practices of different analysts. As a case in point, this paper will examine work domain analysis – the first and most commonly used phase of cognitive work analysis. The most comprehensive accounts of work domain analysis to date are provided by Rasmussen, Pejtersen & Goodstein (1994) and Vicente (1999). While these texts are invaluable resources for work domain analysis and cognitive work analysis in general, the two texts appear to present somewhat different theoretical approaches to work domain analysis. For example, whereas Vicente advocates that the abstraction-decomposition space, which is the main modelling tool for work domain analysis, should not contain representations of activity, many of the models presented by Rasmussen et al. seem to do so. Furthermore, whereas Vicente encourages the use of nouns for representing constraints in the abstraction-decomposition space, Rasmussen et al. often use verbs in their models. Moreover, whereas Rasmussen has indicated that he now believes that the five levels of abstraction that are commonly included in an abstraction-decomposition space are conceptually necessary and sufficient (in Reising, 2000), Vicente argues that there is no reason to believe that the same five levels of abstraction will be relevant to all work systems (also see Lind, 2003).

As well as the texts by Rasmussen et al. (1994) and Vicente (1999), there are numerous other publications on work domain analysis. From these publications, it appears that

there is also some variation in other analysts' approaches to work domain analysis. For example, analysts seem to use different definitions for the five levels of abstraction that are commonly included in the abstraction-decomposition space as well as different approaches for developing the decomposition dimension of the abstraction-decomposition space. These variations may reflect real variations in the work systems that were studied by the different analysts. However, in the absence of explicit statements by the analysts to confirm this, it must also be considered that the variations may reflect the lack of a coherent theoretical and methodological approach for work domain analysis.

Without a coherent theoretical and methodological approach for work domain analysis, researchers and practitioners may find it challenging to develop valid models of complex work domains. Consequently, our ability to design and develop safe, effective, and efficient decision support systems may be compromised. This paper will address some of the theoretical and methodological differences that have emerged in the area of work domain analysis and propose a coherent theoretical and methodological approach for this phase of cognitive work analysis.

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## **20. NORROS, LEENA: DEVELOPING ECOLOGICAL DESIGN OF SMART ENVIRONMENTS**

**Abstract:** The smart objects, environments and infrastructures of the knowledge society should meet the new requirements of systems usability. This claim follows from observations that ICT is a more universal technology than any previous one and it will shape our entire living and working environments. However, because the social dimension is not sufficiently well integrated with the technical in the exploitation of the ICT, its potentials are not effectively and appropriately exploited. Drawing on analysis of the particular new characteristics of ICT technology principles for an ecological design concept are derived. These principles are: 1) Adoption of a monistic approach to human-environment interaction; 2) Focusing on the dynamics of an adaptive human-environment system in design; 3) Understanding usage and design as two functions in artefact genesis; 4) Developing contextual assessment of the appropriateness of the design outcome. Each of these principles needs to be theoretically articulated, and new methods for research and design should be developed. The four principles are going to be elaborated in the discussions of the workshop.

### **20.1 Introduction**

Information and communication technology (ICT) will have profound impacts on all spheres of life, i.e. in everyday life, systems of production, and institutions and culture. New challenges for human-technology interaction (HTI) are expected particularly in the cross-sections between these traditional domains (Tuomi 2001). Traffic and communication systems, agriculture, or wellbeing industries are examples of new expanding HTI utilisation areas.

Technology is conceived as the major driving force for economical growth and wellbeing in the society. Consequently, much effort has been devoted to encourage technical innovations. Several information technology roadmaps identify technologies that may affect HTI and user interfaces (Norros et al 2003, Plomp et al 2002, Ventä 2005). The future ICT is foreseen to enable a combination of high level of user mobility and embedded technology. Multimodal user interface technologies will become available.

Critical analyses indicate, however, that neglecting the user in the design may create a bottleneck in the development of the knowledge society. The technology-push view is becoming balanced by views that stress equal role of social innovations in the development of the knowledge society (Naumanen 2004, Norros et al 2005). It is necessary that the rational relationship to nature that becomes manifest in scientific knowledge would be completed by a rational practical relationship to nature. Such an attitude protects us from technological hubris in our attempts to control the laws of nature by offering a possibility to reflect the long-term effects of technology on the quality of the human life and the living environment (Von Wright 1998).

### **20.2 ICT is a universal technology with instrumental, cognitive and communicative functions**

Compared to any earlier technology information and communication technology (ICT) is a far more general and even universal technology that has practically no alternatives. As such ICT not only changes concrete activities but revolutionises the societal activity

structure as a whole and the complete relations of activity and consciousness (Rückriem 2003). Hence, when we study the usage of ICT it is necessary to consider it both as a tool of making and as a medium of making sense. Hence a comprehensive analysis of ICT considers the tools and media in their instrumental, cognitive and communicative functions.

We made use of the above distinction between the roles of ICT when considering the future HTI research issues in VTT roadmap work (Norros et al 2003). In this connection we found, however, that because these functions of technology are typically tackled within different research traditions, new theoretical challenges emerge when aiming at their holistic understanding. The relationships between theories of human action and activity, on the one hand, and media theories, on the other, need to be revisited and their mutual connections analysed. It has been proposed that systems theory would offer some help in bridging the gaps between theories and in improving understanding of the generic cultural impetus of ICT. In the forthcoming workshop my I shall discuss research and design approaches that could promote such a deeply rational and human-centred development of technology.

### **20.3 An ecological methodology to guide research and design of smart objects and environments**

Human-Technology Interaction research has traditionally focused on the analysis of single tools. This claim applies to both major traditions of HTI, i.e. ergonomics and human factors research that mainly focuses on complex industrial work, and the human-computer interaction research that originated in office work but currently flourishes in the usability analysis of consumer appliances. At the same time as ICT technology has brought the target domains and research issues of these two research traditions closer to each other, we may also identify a further trend. By enabling mobility, embedded solutions and new user interfaces, ICT is transforming work and everyday living environments in a comprehensive sense. It becomes evident that human action does not deal with interaction with separate objects (human-computer interaction) but rather with the ICT-supported smart environment as a whole. Diverse labels have been used for this embedding of ICT in the environment, e.g. ubiquitous or pervasive computing. Consequently, new more systemic approaches are needed to analyse, design and evaluate activity in smart environments (ÄES 2005). Principles of an ecological approach to smart environment design should be created in interdisciplinary work. We have defined four principles that are currently under conceptual and empirical study:

#### *20.3.1 Consider human-environment interaction methodologically as one functional system.*

In the design of smart environments the human-environment interaction (transaction) should, from a methodological point of view, be conceived as one functional system (Ingold 2000, Järvillehto 2000). Such a functional system explains behaviour as being structured according to its results and with regard to the constraints and possibilities of maintaining action. It does not perceive behaviour in simple linear causal relations. Cognition is conceived as embedded and distributed within the elements of the system and intelligence is characteristic of the whole (Hollan et al 2000). Ecological design of smart environments focuses on developing appropriate functional systems.

### 20.3.2 *In the design of smart environments focus on the dynamics of an adaptive human-environment system.*

As the notion of ecology assumes it is necessary to analyse the interactions and developmental dynamic phenomena that take place within the human-environment system. We see it important to develop means to understand the result-oriented organisation of human behaviour in smart environments, to elaborate the organisation by understanding the diverse spatial and temporal connections between different functional systems and activities into which people may be involved simultaneously. In this analysis we consider the environment from the point of view of the possibilities and constraints it provides for action, and, correspondingly, human action from the point of view of the generic dispositions that enable making sense and use of the possibilities. Consequently, the concepts of affordance (Gibson 1977) and habit (Peirce 1998), respectively, are exploited in the analysis of the understanding of the dynamics (Norros 2004). This approach, that considers the generic potential for action and distinguishes it from the description of particular courses of actions opens a way to understand the adaptiveness of human-action.

We also consider that a historical dimension is necessary to understand the structuring of activities. Challenging thoughts of the role of technology in moulding human perception and consciousness were brought up by Marshal McLuhan (McLuhan 1964). By the expression “media is the message” he claimed that media provide the background that shapes human perception and consciousness. We see possibilities to make use of McLuhan’s conceptualisations of the generic dynamics of the influence of technologies (McLuhan & McLuhan 1988). Particularly relevant may be to consider his ideas of the nature of electric medium. According to McLuhan it is the role of the artists to reveal the impact of media on our perception, thinking and action. Without artists, human actors merely adapt to their technology, he claims. Human-technology interaction research should be able to learn from the arts and artists and strive for the articulation and understanding of the immediate background effect of technologies.

### 20.3.3 *Consider usage and design as two functions in artefact genesis*

There are three issues that every approach within HTI research has to tackle. The first is to conception of design, the second the conception of the user activity (which was discussed above in point 1), and the third the conception of interaction between design and usage (Carrol 1997). In developing the ecological design it is necessary that we analyse our relationship in all these issues.

Design is today usually considered as an iterative process. This definition of the process of design is of course an important starting point. We claim, however, that the current design concepts could benefit from extending their definition of what is the object of design. We see that today the product is usually conceived as the object of design. Consequently, design process itself will be tackled as a very tightly constrained linear (even though iterative) process of actions that enable the production of the result. It will also be evaluated against well-defined success criteria and the quality of the design process is defined through a good controllability of the process. If the object of design is comprehended as creation of new possibilities for human activity the process becomes much more uncertain but also creative. This is what so called concept design is all about. There are examples that show that leading manufacturers in particular domains have

adopted concept design as a tool to project their future business activities and to vision new ways and values of usage (Keinonen & Jääskö 2003).

Interaction between design and usage is, of course, long been identified an important issue in good design. This principle is already implicit in the concept of iterative design. We claim however, that these two activities have often been treated as interacting with each other in a more or less external manner, without themselves itself becoming pressed to transform in this interaction. Design is treated from a process point of view, usage sporadically via user tests. In the ecological design concept that is more and more interested in creating new possibilities and ways for living, it also necessary to pay more attention to understanding the activity by which these possibilities may be created.

The approach that has been coined the instrumental genesis approach (Beguin & Rabardel 2000) advocates the idea of parallel development of activity (instrumentation) and the tool (instrumentalisation). This process takes place in a collaborative process in which both designers and users are active actors and undergo a learning process. In our own studies we have been able to describe and verify the learning processes of users with reference to their subjective disposition to the developing instruments and their conception their own role as users (Norros 1996).

#### 20.3.4 *Exploit an integrated contextual assessment of the appropriateness of the design outcome*

Evaluation of usability of artefacts is an existing practice in human-technology interaction research. It should be no surprise that in an ecological design approach new evaluation concepts must be developed. More problematic is to comprehend how the present evaluation processes, practices, indicators and criteria should be developed so that they would grasp essential features of goodness of smart environments. In the following, some tentative ideas are brought up.

In our own ongoing work we have used the concept of systems usability as a tool of incorporating the developing evaluation concept (Savioja & Norros 2004, Savioja & Norros 2005). The notion systems usability indicates, first, the need to comprehend the smart artefact or environment in a holistic manner. The artefact will, according to our ideas of the technological nature of ICT, serve the above mentioned three basic functions at the same time. These were the instrumental, the cognitive and the communicative function. Accordingly, it is necessary to reflect the artefact from all these points of view.

We see further that in order to succeed in such an integrated evaluation the artefact must studied in usage. Consequently, contextual and performance-based assessments are necessary. We exploit the semiotic meaning relationship model of Charles Sanders Peirce (1991) to develop a contextual evaluation basis for artefacts. Hence, we consider the presentation of user interface, content of information and the user performance in connection with each other (Savioja & Norros 2005). We developed this approach on the basis of our work on users' practices, and found that corresponding ideas specifically with relation to interface design were proposed and developed by Woods (Woods 1995).

In developing the performance-based assessments we have proposed a conception to distinguish between outcome evaluation and evaluation of practices. The former is seen to express what has been called external good of practice, whereas the latter focuses on

what is considered as internal good of practice (MacIntyre 1984). The latter features, and habit-related indicators developed from them, are definable only by, and, in co-operation with the practitioners. They enable projecting the future potentials of the artefacts and usage.

The most important integrative indicator in the performance-based assessment is connected to experiences of the users and, also the designers, of the potentiality of the concept or the designed product to become a part of a significant practice. This indicator is emotionally-laden, which is the strength of the indicator. (Battarbee 2004, Norman 2004). It may namely be argued that the users will experience a positive emotion when they, as experts of their work and everyday life, identify a genuine new possibility of action. The evaluator should, however, remember that when seeking proof of such experiences it should be necessary to consider the effect of the artefact in both scientifically rational and practically rational sense, as G.H. von Wright would demand of a truly humanistic development of technology.

In conclusion following generic research challenges for constructing smart environments may be identified:

#### **20.4 Conclusions**

- Analysis of what are the ecologically critical features of the new environment and how they shape human perception and thinking
- Methods for defining context, functional analysis of the domain and tasks
- Research on new skills, competencies and new forms of learning
- Conceptualisation and structuring human-technology team work
- Deepening the comprehension of user acceptance of technology
- Improving understanding of artefact genesis and designer's work to improve the innovativeness of design
- Development of evaluation dimensions and acceptance criteria of systems usability
- Understanding technological diversity and integration in improving the viability of the human-environment systems and promoting sustainable development

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## **21. NYSSSEN, ANNE-SOPHIE: WORK ANALYSIS FOR DESIGNING TECHNOLOGY - INTEGRATING THE PSYCHO-SOCIAL ORGANIZATION OF WORK TO SUPPORT THE DESIGN PROCESS**

During the last two decades, system engineering has been largely influenced by the development of 'Human Factors' approaches attempting to incorporate the user's needs into the design process.

The first source of influence was Cognitive Psychology. Its progressive influence is traceable through the evolution of the 'politically correct' concept of the time: from 'experts systems', through 'intelligent decision supports', 'prostheses', to 'control tools'. In some way, this vocabulary shift reflects the growing humility that designers had to acquire when trying to mimic complex human cognitive activity. Not surprisingly, cognitive activity analysis was then placed at the center of this approach, focusing on information processing, mental resources management, decision making and adaptation.

The second source was the Scenario-Based Design approach, stressing the user's contextual point of view. One key element in this perspective is the user-interaction scenario, a narrative description of what people do and experience as they try to make use of systems and applications.

Despite these valuable insights, both approaches mentioned above suffer from some incompleteness when taken separately. For example, they disregard the psycho-social organization of the work system, focusing on the user's performance and interactions with the device rather than on the system performance. I share the contention initiated by the so called 'French Speaking Ergonomics' that only a work analysis conducted with a global, systemic, point of view can identify the critical dimensions of the work system performance that must be integrated in the design process in order to respond to the actual user's needs under real constraints, hence facilitate the appropriation of the designed tool by the end-users within a work organization. A set of different techniques is necessary to acquire a proper understanding of these work constraints: field observations, questionnaires, interviews, simulation.

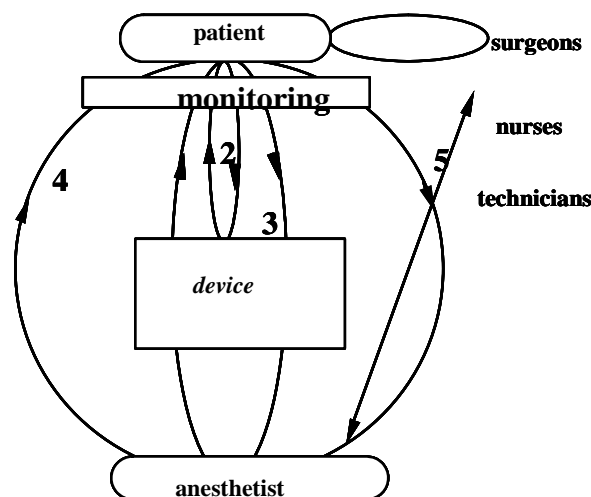
Hereafter, I discuss two studies conducted in the medical field, to illustrate how important a comprehensive work analysis is for the design of new technology in order to anticipate the impacts on the work system performance and attempt to compensate them. The first one is about the impact of a new automatic drug device intended for anesthetists, and the second one deals with the impact of a new robotic surgery system intended for surgeons. Interestingly, each of these tools has been designed for a specific group of users (one for anesthetists, the other one for surgeons), in one same space (the operating room), performing a collective activity. More than 600 hours of observation were conducted in the operating rooms, as well as on simulated tasks, to assess the impact of introducing these artefacts through an extensive work analysis.

In case 1, the work analysis showed that, while the new tool was supposed to merely decrease the monitoring task of the anesthetist towards the patient, because the device was using a specific drug (Propofol) with different pharmacokinetic characteristics (blood pressure reducer with short half-life), it actually influenced the global work system performance:

- creating, for the anesthetist, a new monitoring task directed towards the device itself,
- imposing that a new way of thinking be developed by the anesthetists and by the nurses (dosage (mg/kg/h) had to be transformed into desired plasmatic concentration),
- disturbing the communication protocol, as this new thinking was only valid for the drug (Propofol) used by the device. The anesthetists still communicate and work in terms of mg/kg/h for the other drugs.
- increasing, for the anesthetists and the surgeons, the frequency of the monitoring of the blood pressure,
- changing the planning task because of the short half-life propriety of the drug,
- reporting the monitoring of the critical awakening phase to a next locus and to a next person,
- disturbing the surgeon's work because the short lasting drugs effect demanded that the feeding lines be as short as possible, hence the device be as close as possible to the patient's body.

In brief, the very act of introducing the new tool for the anesthetist had a considerable and unanticipated, while perfectly predictable, impact on the system key performance constraints, affecting monitoring and planning activities, leading to the introduction of additional control loops (Fig 1), and affecting the psycho-social organization of the work and the cooperation:

Fig.1 – Loops of control of the H-M system.

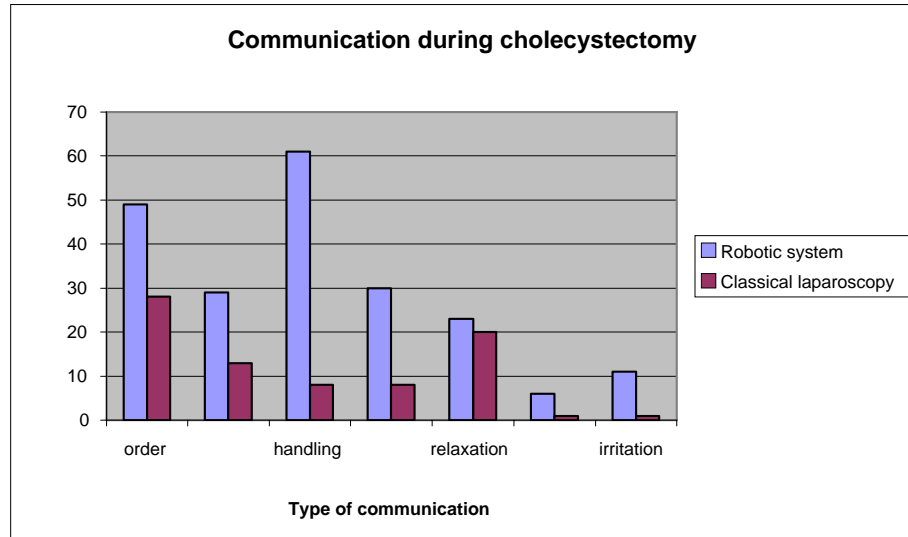


In case 2, work analysis showed the impact of the surgery robotic system on the physical and social interactions between the actors of the operating room (surgeons, assistant surgeons, anesthetists, technicians, nurses):

- The use of the robot implies new knowledge and new protocol not only for the surgeon but for the whole operating team relative to the placements of the instruments and the preparation of the robotic system.
- Although the robot gives a three-dimensional image to the surgeon, the team still works with a two-dimensional picture, creating a rupture in the collective representation of what's going on. Overall, the need for communication is significantly increased by the robot, as shown by Fig 2 below.
- The distance introduced by the system between the surgeon and both the patient and the rest of the team changes the role of the members of the team. There are two new actors in the team: the robot and the technician who become essentials within the team. The surgeon assistant becomes more like a technician and is sometimes replaced by the technician.
- The arms of the robot are very cumbersome which makes the conversion, in case of problem, quite awkward.

Here also, the introduction of the new tool had a considerable and unanticipated, while perfectly predictable, impact on the psycho-social organization of the work and the cooperation. This plays a large role in how the end-users and the team perceive, accept and use the device within the organization.

Fig. 2 - Comparison of communication between robotic and classical laparoscopy surgeries.



These two studies insist on the importance for designers to assess the impact of the new tool from a global, systemic point of view, taking into account the psycho-social organization of the work, rather than only the user's point of view. Only work analysis using different techniques to collect data (field observations, questionnaires, simulation) can provide a useful window into the work system performance, the work constraints, and thereby a systematic basis for designing devices that workers need and use within the organization.

## **22. PETERSEN, JOHANNES: INTEGRATION AND INTERPRETATION OF DATA FROM COMPLEX WORK DOMAINS**

In process control it is important that operators can identify the state of the work domain in any situation based on representations of the work domain mediated by the supervisory control system. Therefore the design of representations of the work domain that can support the integration and interpretation of data, as well as reasoning, has played a major role in the Cognitive Systems Engineering tradition (e.g. (Woods & Roth, 1988)).

Representation design involves considerations about aspects such as: 1) Domain Content: the work domain properties that need to be captured, 2) Content Form: the type of representations used to capture the relevant work domain properties, and 3) Expression form: the physical expression of the domain content in the human-machine interface. For a discussion of these distinctions from a semiotic point of view see the position statement by Michael May.

This position statement focuses mainly on the second aspect – content form. Different layers of representational types are described, and their role in the data integration and interpretation process is discussed. Furthermore, links are drawn to the Abstraction Hierarchy and Ecological Interface Design (EID).

### **22.1 Three layers of representational types**

Petersen (2004) describes the relations between three layers of representational types (the so-called three layer model) and their role in the data integration and interpretation process. The different layers of representational types are: 1) variables, 2) constraints (relations among variables), and 3) relations among objects. The bottom layer contains system variables referring to dimensions of the work domain. The upper next layer contains constraints describing relations between variables and at the upper-most layer the work domain is represented in terms of objects that interact causally.

It is important to emphasize that the symbolic reference of the representational types in the three-layer model depend on the actual conceptualization of the work domain. For instance, an object-centered description may refer to functions of physical components or systems.

Constraints, specifying proper functioning of the work domain, are fundamental in order to cope with unanticipated events (e.g. (Lind, 1981) (Vicente and Rasmussen, 1992)). In the three-layer model such constraints are related to an object-centered description of function. Typically the relations between the object-centered layer and the constraint layer are many-to-many. That is, several constraints may be needed to specify the proper functioning of an object-centered function description and the same constraints may be used to specify the proper functioning of several functions.

Multilevel Flow Modeling (MFM) offers an object-centered language for description of the functional structure of complex technical systems (Lind, 1999). The object-centered representations offered by MFM are linked systematically to a constraint description. See Petersen (2000, 2001) for an account of causal reasoning based on MFM.

## 22.2 The link to the Abstraction Hierarchy

According to Rasmussen (1986) operators supervising a complex system need to attend to system representations at different levels of means-end abstraction. The means-end abstraction levels imply different conceptualizations of a work domain and the three-layer model may, in principle, be instantiated at any of the means-end levels. In other words, the means-end abstraction levels proposed by Rasmussen and the different layers of representational types described above are orthogonal. The former focuses on the content of the work domain, whereas the latter focuses on the relevant content form, i.e. how the work domain content is represented.

## 22.3 Generic inference steps

This section is concerned with inferences in the data integration and interpretation process. Generic inference steps, defined on the basis of the different layers of representational types described above, are proposed. Lind (1988) has used a similar approach to illustrate the integration and interpretation process in MFM.

At the variable layer, data reflect the quantitative and qualitative value of variables, at the constraint layer data reflect the state of constraints, and at the object-centered layer data reflect the state of objects. Below the different generic inference steps are described.

**Integration.** Integrating variables into (higher-order) variables (e.g. velocity is based on two variables: distance and time)

**Derivation.** A (multivariate) constraint can be used to derive the value of a (higher-order) variable from the values of known variables (no matter whether these are directly measured or derived).

**Variable state identification.** A single variable constraint (e.g. defined by minimum and maximum values) can be used to identify the state (qualitative value) of a variable (e.g. low/normal/high).

**Constraint state identification.** Based on the value of the variables entering into a constraint, it is possible to identify the state of the constraints (violated/not-violated). When the values of the variable are inconsistent with the constraint defining the interrelations between the variables, the constraint is violated.

**Object (function) state identification.** Based on the state of constraints (violated/not-violated) it is possible to identify the state of object-centered functions. If the constraint(s) specifying the proper function is (are) violated the function is failed, otherwise the function is ok.

**Causal reasoning based on an object-centered model.** Reasoning about the state of the work domain based on an object-centered model representing causal relations among objects.

The inference steps just described reveal different outcomes of the comparison process between data and constraints that specify proper functioning. For single variable constraints, for instance, the comparison process may result in a classification of some variable value, an identification of the state of a constraint, or an identification of the state of an object-centered function. In the first case, the quantitative value of a variable is transformed into a qualitative value (e.g. low/normal/high). In the second case the

quantitative value of a variable is used to identify the state of a constraint (violated/not-violated) and in the third case the value of the constraint state is used to identify the state of a object-centered function of the work domain (failed/ok).

In unfamiliar situations it is crucial that operators are aware of the implications of a violated constraint in terms of disturbed goals and functions at the object-centered layer. It is important to support reasoning about causes and consequences at a plant-wide level based on a representation of goals and functions of the work domain. This requires a specification of the relation between the object-centered description of functions (and goals) and the constraints specifying proper functioning.

## 22.4 The link to EID

In the literature describing applications of EID it is hard to find discussions of different types of representations of the work domain and their interrelations. Sometimes the focus is on constraints: “Because the system was built in a certain way, for a certain purpose, there will be certain relationships between variables. These relationships can be described as constraints.... [the abstraction hierarchy] provides a framework for identifying and integrating the set of goal relevant constraints that are operating in a given work domain. Each level in the hierarchy represents a different class of constraints...” (Vicente and Rasmussen, 1992, p. 592) and sometimes the focus is on relations among objects: “The AH was used as a basis for developing a formal representation of DURESS. DURESS was described in terms of objects which comprise the system at each level of abstraction, along with the means-end links connecting those objects across levels” (Bizantz and Vicente, 1994, p. 88). Apart from a few exceptions (e.g. (Reising and Sanderson, 2002) and (Liu et al., 2002)) representations of the variables, constraints and relations among objects are typically separated (see e.g. (Bizantz and Vicente, 1994) and (Ham and Yoon, 2001)). According to the authors knowledge the EID literature offers no systematic treatment of the combination of constraint and object-centered representation.

A prototypical EID interface focuses on work domain constraints and displays variables in a way that allows the operator to compare perceptually, based on geometrical constraints in the interface, the current behavior of the work domain with the behavior that is expected from the work domain constraints (e.g. (Vicente and Rasmussen, 1992)). EID is opposed to a traditional one-sensor-one-indicator interface which simply shows the values of the sensed and derived variables by means of separable dimensions. It is a well-known fact that a one-sensor-one-indicator interface provides poor support for operators supervising a complex work domain because it leaves operators with the burden of integrating and interpreting data.

A complementary approach to interface design, supporting causal reasoning at a plant-wide level, would be to make explicit the result of the comparison process between current and expected behavior in terms of the state of object-centered descriptions of system functions. In this approach the constraints only have a secondary role to play, serving as means for state identification of object-centered functions (refer to the inference steps described above).

Actually, interface design, based on an object-centered description of function, is mentioned implicitly in the theoretical basis of EID. More specifically, for interaction at the knowledge-based level, it is argued that the operator is supposed to have access to

an abstraction hierarchy representation of the work domain, given in terms of relations among objects. Nevertheless, this type of representation is almost never considered in the applications of EID. Furthermore, the visualization of object-centered representation, based on some expression form, is not treated systematically in the EID literature. Obviously it is not feasible to use geometrical constraints for the presentation of object-centered content form. Instead, some sort of diagrammatic representation format would probably be useful. For a general discussion of the mapping between domain abstractions and interface representations see the position paper by Michael May.

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### 23. PRITCHETT, AMY: 'PROCEDURES' AND DECISION SUPPORT

Several times as part of an afternoon's work I have read descriptions of "procedures" as normative task structures imposed on workers by some entity remote from the workers both geographically and in terms of awareness of the worker's context. Each time, I then crossed off 'Read paper' on my day's to-do list, and maybe wrote out a list of errands to do on the way home -- a shopping list for that night's dinner, perhaps -- to take with me at the end of the day. Perhaps I am unusually anal (I would prefer to say 'organized'), or perhaps I am compensating for a weak memory (I would prefer to say 'absent-minded') - - but I would like to discuss how we view 'procedures' as a construct relative to the design of cognitive aiding.

Has the literature typecast procedures in an overly narrow sense? I think so. I have agreed with all the examples given of 'bad procedures' and 'over-reliance on procedures', yet I also find in my own research -- and day-to-day activities -- many positive roles for procedures. Some of these roles are certainly bad and should be prevented: the perils of imposing contextually-inappropriate normative work structures has been well documented, yet my own recent research into decision aids for airline 'schedule-adherence managers' has found the same implicit and pervasive in technologies intended to 'help'. However, other roles of procedures are effective or, in some cases, vital. In my main research domain, air transport cockpits, proper procedure following is a sign of professionalism; correspondingly, the procedures are carefully constructed, vetted, debated and re-designed with pilot input, and are held in common as a resource providing a demonstrably-safe task progression through an otherwise under-constraining physical environment. When teaching, lab procedures establish a scaffolding for students, quickly getting them participating in complex tasks they could not otherwise perform; from this viewpoint, instruction is knowing when and how to fade out the procedural scaffolding as students' conceptual understanding grows. As an engineer, I believe the best procedure to achieve an end is best framed as a subject of analysis, research and design -- and as a product which can encapsulate many salient affordances and constraints in the environment.

In addition, now that I find myself introspecting on my day-to-day activities as part of a team effort (i.e., two career professionals becoming parents and needing to run a household through coordinated behaviors), procedures also serve to provide a 'co-ordination-structure' to our environment that the physical environment alone can not afford. Why is it a red traffic light that constrains forward travel (hopefully) and a green light that affords travel? It is not to enable me in isolation to run my errands in the evening, but instead to coordinate our collective activity through prescriptions and proscriptions on individual behaviors. We could build physical structures into the environment to create these constraints and affordances -- traffic barriers, perhaps, that swing into place in lieu of red lights, physically obstructing traffic -- but we find that procedures often satisfy the purpose with little or no tangible manifestation. Using them, I can drive to the grocery store using pre-coordinated behaviors, and I can form expectations such as whether crossing traffic will stop or continue.

A procedure may be judged on its level of detail, its comprehensiveness relative to operating context, and its accuracy. It's hard to find a procedure that scores high on all three metrics; at a minimum, an 'effective' procedure must be 'accurate', by which I mean it must prescribe or proscribe behaviors as appropriate to achieving goals within

the environment. Decision aids, then, may use these prescriptions and proscriptions as structures to mimic established work practices and to scaffold novice behavior (or behavior in novel situations). In addition, a well-designed procedure needs to be created through examination of the environment, and thus has many contextual relations implicit to it. My list of errands may put 'pick up laundry at cleaners' first and 'buy ice cream' last due to the former's proximity to my starting point and the latter needing to be driven quickly home before it melts in the Atlanta heat. Our common representation of a procedure -- a check-list or do-list for example -- may not display these affordances and constraints, but a decision aid can. In addition, a decision aid can make them explicitly situate them relative to recognizable behaviors and desired outcomes.

## **24. RIZZO, ANTONIO; POZZI, SIMONE; SAVE, LUCA: DESIGNING THE EVOLUTION OF INTENTIONAL AFFORDANCES**

### **24.1 Introduction**

As it is widely recognised by theoretical approaches as distributed cognition (Hutchins, 1995) or activity theory (Nardi, 1996), an IDSS does not need to be a complex software system. Rather any tool that supports the human activity can be defined as an intelligent support to the decision, because by modifying the tasks in which the human actor is involved it also affects the nature of his/her decisions. In the last 20 years, the ambitious expert systems designed in the Seventies have given way to more focused, narrow, in a sense specialised support tools. Full automation is no longer pursued, as it proved to be unable to handle complex and dynamic work settings and demands, not showing the requisite flexibility. The design objective has moved to provide the human actors with different types of supporting tools that can be opportunistically adopted and requested in different conditions. As a consequence, the flexibility of the intelligent support tools has increased. IDSS can now be exploited even in front of highly variable environmental conditions, whilst the typical expert automated system had not been able to efficiently adapt to conditions outside of the designed space. The variety and number of the support tools are better suited to effectively cope with varying conditions and dynamic environment.

In the current context, the core design issue is no longer to provide support for the correct application of rules, nor to inform the meta-level selection of the correct set of rules. Rather, it has moved to foster the identification of appropriate goals considering the available tools. This process may also imply the adoption of tools for different purposes than those originally intended. In this respect users can go beyond what was expected and foreseen by the tool designer and can devise additional and innovative interaction modalities.

The history of technology offers plenty of examples of creative uses, of shifts from one original intended use to completely new ones. For instance, the first audio recording and playback device (the Edison's phonograph) was designed to preserve and distribute personal vocal notes and audio documents in work settings such as lawyers' offices. However, the actual development of this technology evolved in a completely different direction. A similar competing technology (the gramophone) was used to reproduce over and over standardised contents (e.g. popular songs, operas and classical music) and to distribute them to wide audiences. This finally ended up with the death of the phonograph as a commercial product, with the gramophone becoming the market standard. In other words, a recording device turned itself into a playback support for entertainment. Paradoxically, the opposite direction is nowadays followed by the fashionable iPod(iTunes. iPod was conceived and designed simply as an advanced digital walkman. Instead, a growing number of users started recording their own personal notes (e.g. comments to modern art exhibitions, news and discussion on innovative technologies, etc.), to share and distribute them via dedicated web sites (a practice known as Podcasting, from iPod and broadcasting).

### **24.2 Theoretical foundations: the cultural-historical psychology**

The continuous shift of the artefact use has been theorised by cultural-historical psychologists since the beginning of the 20th century. The cultural-historical approach

recognised that tools cannot be considered in isolation from the human activity in which they are exploited (Vygotskii, 1978) (Wertsch, 1985). Tools and human activities should always be considered in a dialectical relationship. By being part of human actions, a tool gets modified by the activity and modifies the activity itself.

In this line of reasoning, taking the right decision is no longer finding the solution within the boundaries of a given configuration of tools, goals and environmental conditions. Dynamic and complex settings require the adoption of an opportunistic strategy in the evolution of tools and goals. The aim of an IDSS can thus be rephrased as supporting the user in structuring the appropriate configurations of tools-goals. In details, this also implies the awareness of the dialectical relationship between tools and goals. This can be achieved by knowing the design rationale of the tool (i.e. why the designer made the tool as it is) and past instances of tool use in socio-cultural contexts (i.e. how previous users used the tool).

To address this issue, within the cultural-historical approach (and our revised unit of analysis, Rizzo, et al. 2004), we propose an elaboration of the concept of affordance based on the work of J.J. Gibson and M. Tomasello.

### **24.3 Bringing opportunities of action to the front: the concept of intentional affordances**

An affordance may be defined as an action opportunity in the world, for a human actor that has specific sensory-motor capabilities. The key point is that the concept of affordances is of a relational nature. An affordance does not exist independently in the world, but only as an interaction possibility between an actor's capabilities and the world. The present paper will propose to further articulate this initial definition and to distinguish (i) sensory-motor affordances and (ii) intentional affordances.

The category of sensory-motor affordances is derived from the works of Gibson (Gibson, 1979), who first introduced the concept to explain the way humans visually perceive the world. For this position, an affordance is a property of the world which is compatible or relevant for people's interaction. Thus sensory-motor affordances are those object properties that afford manipulation by an actor (e.g. grasp, pull, raise, etc.). This type of affordances is related to the human capabilities as developed phylogenetically in the human species, or ontogenetically in a specific human actor.

However, we may also refer to Tomasello (Tomasello, 1999; Tomasello, Carpenter, Call, Behne, & Moll, in press; Tomasello & Rakoczy, 2003) to identify a second type of affordances. Working in the domains of comparative psychology and child development, Tomasello proposed to name as intentional affordances those object properties that are derived from the cultural uses of an artefact. Quoting Cole (Cole, 1996), Tomasello highlights that by being part of human activities artefacts get modified and acquire an "ideal part". This part conveys the cultural habits, social conventions and knowledge about a tool use, i.e. those interaction modalities that derive from the ways people interact with that tool in the socio-cultural environment, rather than from the physical properties of an object (i.e. what we have named as sensory-motor affordances). The existence of intentional affordances enables users to place themselves in the "intentional space" of other users, discerning others' goal and what the others are using the artefact for. Whereas sensory-motor affordances are phylogenetically determined, intentional affordances derive from the socio-cultural dimension.

At this point, it is worthwhile distinguishing between the existence of an affordance and the information that makes it perceivable. As clearly stated by Gaver (1991), the two dimensions are independent and there are cases where affordances are not visible but still exist, or on the contrary cases where there appears to be an affordance that is not actually present. This is different from the use of the category that was made by Norman (Norman, 1988) to explain how people can interact everyday with a large number of artefacts without apparent efforts. As a matter of fact, Norman merged the two dimensions and stated that affordances guide in the use of tools by making apparent the possible ways of interacting with it. According to Norman, the designer's task is to manipulate affordances to support users in making the correct actions and to make some actions easier for the users. In other words, users should be guided in the use of tools by making apparent some selected ways of interacting with it.<sup>1</sup> Instead, in our proposal we would like to maintain the difference between the existence of the affordance and its visibility, to clearly distinguish two different domains of design intervention. On one side, affordances can be modified or created by design, but design efforts can also focus on the information on the affordance as perceived by the user. Furthermore, while affordances are resources that the environment provides (afford) to a given person and that this person may (or may not) attend to and use, information for affordances are events that include environmental features, the activity of the organism, and the consequences that ensue as well as the relations among these (Gibson, 2000).

Thus we have two ontological, but interrelated, type of affordances (sensory-motor and intentional) and two different components for each type of affordance (resources and events).

#### **24.4 Intentional affordances from the designer's perspective**

From the designer's perspective, this view opens new space for design, new spaces for mediating human activity in a more robust way, oriented toward a closer participation of people to the evolution of artefacts and human practices. In the presentation we will provide empirical evidences (coming from comparative psychology, neurophysiology, and interaction design) supporting this conceptualization of affordance and its relationship to our revised cultural-historical unit of analysis. Finally we will conclude with an example from our own experiences in designing innovative environments for Air Traffic Management.

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**25. SANDERSON, PENNY**

## **26. SCHULTE, AXEL: COGNITIVE AUTOMATION AS A SYSTEMS ENGINEERING APPROACH TO INTELLIGENT OPERATOR ASSISTANCE AND AUTONOMOUS VEHICLE GUIDANCE**

Today's automation systems are typically introduced into work systems as operation-assisting means and, therefore, being tools to the human operator to fulfil certain well defined sub-tasks as part of the work process. The human operator is in the role of the high end decision component determining and supervising the work process. With emergent technology highly automated work systems can be beneficial on the one hand, but automation may as well cause its own problems.

A new way introducing automation into work systems shall be advocated by this statement, overcoming the classical pitfalls of automation and taking benefit, simultaneously. This shall be achieved by so-called Cognitive Automation (CA), i.e. providing human-like problem-solving, decision-making and knowledge processing capabilities to machines in order to obtain goal-directed behaviour. A key feature of a cognitive system is the ability to create its own comprehensive representation of the prevailing situation on the basis of knowledge and observation and to process superior goals for acting. Thereby, this kind of systems are enabled to support the human operator in supervision and decision tasks, then being an operation-assisting means understanding the whole work objective and heading for the achievement of the overall desired work result. Programmed to pursue goals for co-operation and co-ordination (e.g. task coverage, avoidance of redundancy or team mate overcharge), and implemented the understanding of the situation (e.g. opportunities, conflicts) and actions of the team mates (human or machine likewise), such cognitive systems will emerge as artificial co-worker within the work system, either being an intelligent machine assistant to the human operator in his work place or functioning as an autonomous intelligent agent within system-of-systems environments. Even applications as automatic, intelligent tutoring systems are imaginable.

In any case, an Artificial Cognitive Unit (ACU) has to be created and furnished with the relevant capabilities (i.e. knowledge) for the task domain, including the capability to co-operate and function in a team. In order to achieve this, several aspects have to be considered:

- An appropriate theory of cognition has to be chosen or developed. In our case the so-called Cognitive Process (CP) will be the theoretical approach incorporating the processing steps of information gathering, interpretation, goal determination, planning and execution as well as a structure for partitioning the required knowledge according to several criteria, such as a-priori knowledge and situational knowledge, knowledge specific for the different processing steps (e.g. belief, goals, plans), knowledge specific for certain application aspects (packages).
- An appropriate knowledge modelling technique has to be worked out. In our case it is the so-called Cognitive Programming Language (CPL), based upon Soar (State, operator and result), being an object-oriented layer on top of it. CPL allows the knowledge structuring according to the abovementioned (belief, goal, plan).
- Appropriate knowledge acquisition and elicitation techniques, including machine-learning approaches have to be found and adapted to the application-specific needs.

- An appropriate system engineering tool implementing the CP has to be developed in order to combine knowledge packages into an application, to interface with the environment, to generate behaviour in terms of a real-time process from declarative knowledge representations (i.e. inference), and to provide development support such as debugging. The Cognitive System Architecture (COSA) developed at our institute offers an engineering solution to these requisitions, presently being used in technology demonstration programmes.

Currently, we are conducting several research projects making use of these considerations. Demonstrator systems are being developed in the fields of air-crew assistance for tactical helicopter missions (civil and military), machine-machine co-operation for autonomous UAVs (Uninhabited Aerial Vehicles) and manned-unmanned teaming of remote operators and UAVs.

**27. SHARPLE, SARAH (WITH COX, GEMMA & STEDMON, ALEX):  
CHALLENGES IN IDENTIFYING DECISION SUPPORT  
REQUIREMENTS IN DISTRIBUTED COLLABORATIVE SYSTEMS**

Initiatives have been proposed and implemented that will affect the decision support requirements in a number of safety-critical distributed collaborative systems. This statement and paper will discuss the challenges presented when attempting to identify the impact of introducing such technology in two safety critical environments: Pilot-air traffic control collaboration, and railway signalling and control.

A number of projects based in the Institute for Occupational Ergonomics have attempted to identify the introduction of technologies such as automatic route setting for railway control, to freeflight and datalink in air traffic management. These projects have taken two methodological approaches: laboratory trials that aim to examine key elements of the workplace in a controlled manner; and fieldwork that takes a joint cognitive systems perspective to identify the existing and potential impact of these technologies. This statement will consider the relative benefits and pitfalls of these approaches and examines how a combination of laboratory and fieldwork can best be implemented when identifying decision support requirements. In addition, the particular features of the two safety critical environments of interest are considered and their impact on the granularity of data collection and analysis that is possible both instantaneously and retrospectively are discussed. Examples of the data collected and findings obtained will also be presented.

## 28. SVENMARCK, PETER: PRINCIPLES FOR EFFICIENT HUMAN-ROBOT COORDINATION

Many types of robots are currently being developed for military applications, such as reconnaissance, electronic warfare, logistics and armed operations. Although the characteristics of human operator control in these applications are certainly different, spanning from mere remote piloting to supervisory control of robot-integrated automation, they all share the problem of how to achieve coordination between the operator's and robot's understanding of the situation as well as coordination concerning appropriate action. Addressing the coordination problem requires a deliberate balance between robot automation, information presentation, decision support, and display and control technologies that considers how the human-robot system as a whole adapts to task complexities.

Hollnagel (2005) and Hollnagel and Woods (2005) characterise the task complexities of human-robot systems as requiring four layers of control where tracking keeps the system within predetermined performance boundaries, regulating achieves short-term goals, such as specific manoeuvres, monitoring of the system state relative the environment for initiation of action or goal setting for the tracking layer, and finally targeting for achieving mission goals. Additionally, there are interdependencies between the levels of control where tracking may provide input that is necessary for the situation assessment required for targeting. Typically, at all levels there are also interdependent tasks for control of the robot and the payload. An understanding of these interdependencies is important to avoid problems of automation surprises and out-of-the-loop performance when partly autonomous robotic functions are introduced. Further, autonomous functions often changes the character of the human-robot coordination problem from compensating for impoverished perceptual cues and coordination of direction of gaze and direction of movement in remote piloting, to a more sophisticated coordination that requires knowledge of automation state and performance boundaries. The limiting factor for all types of coordination problems is in practice, however, the amount interaction that is required to achieve coordination (cf. Sarter, Woods, & Billings, 1997).

Although the layers of control may give a reasonable account of the task complexities there is currently a need for empirical studies of the task interdependencies for some actual human-robot systems. A discussion of suitable methodologies for analysis of some actual levels of control, as well as how to characterise the interaction for coordination would therefore be greatly appreciated.

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**29. SVENSSON, ERLAND**

### 30. TANGO, FABIO: CONCEPT OF AUTONOMIC COMPUTING APPLIED TO TRANSPORTATION ISSUES: THE SENSITIVE CAR

Mobility is a key-factor in modern economics (with more than 10% of gross domestic product and more than 10000000 people employed) and thus all studies and researches about run towards a safety and efficiency. On the other hands both society and customers request for it; in fact, the number of road victims is unacceptable high (in year 2000 over 40000 people died in Europe and 1700000 were injured) with excessive social costs (direct measurable cost of road accidents is in the order of 45 billion Euro and indirect cost is 3-4 times higher; annual figure is 16 billion, that is 2% of the EU's GNP).

All this creates a demand for safety: benefits from technology are expected and the introduction of Advanced Driver Assistance Systems (ADAS) aims at dealing with such a problem, since they can have a strong effect on traffic safety. It is anyway true that, in order to achieve this goal, an integrated approach is necessary, involving new technologies, infrastructure improvements and increasing co-operation between public and private sectors. In the current situation, most of ADAS applications are used for comfort functions (e.g. ACC, Parking Aid) in given scenarios (e.g. highways). Until now, technical limitations and a lack of integration of the actual systems have prevented their wide diffusion, since they still show high costs and also they are not really fitting the user's needs. Let's consider the example of FCW: due to limitations in recognizing overheads objects, a limit in the maximum range at which fixed obstacles can be taken into account is necessary (typically, not more than 50 m). The result is that on one hand there is the risk to have a very low acceptability rate by users due to too high number of False Alarms; on the other hand, the anti-collision system stop supporting drivers just when they need more!

The challenge **NOW** is to use available technologies in order to really support the drivers; this can be done if the systems are able to ***understand and cope with their own limits*** involving three main aspects:

- ❖ *on sensors*
- ❖ *on scenario and its assessment*
- ❖ *on system design*

All this means that the system, receiving information from outside of the vehicle, the systems will be able to assess the risk of an accident happening and support the drivers by means of an advanced and dynamic in-car machine-human interaction, able to let the exchange of essential safety information between humans, vehicles and vehicle-infrastructure

A conceptual framework on which this is based, can be represented by the concept of **Autonomic Computing**, a paradigm for the design of systems and applications able to cope with strong complex environment by means of strategies similar to those used by biological systems. An example is given by an homeostatic system, which is a system able to react to the environmental changes with a set of equal and opposite changes, in order to obtain an internal balance.

Thereby, in other words, these systems can pursue their goals by means of principles used by the (human) autonomous nervous system. This involves the computational systems, but it can be enlarged to complex technological systems, with a wide range of applications in different fields: automotive, aeronautics, healthcare, etc.

In particular, let's consider the first one; users can be very good to manage "ordinary situations", but what happened in case of unknown and potentially critical situations? All static show that more than 90% of accident is due to human (wrong) behaviour, so it is clear that in most of these cases drivers have chosen the incorrect actions to take (of different kind and involving different steps and areas, from perception to execution → CACCIA). In this context, the system can help the drivers in such unknown situations, showing (at least) the consequences (sometimes dramatic) of the actions that a user wants to take, because it is able to understand and anticipate them in advance, since very often when drivers become aware, it is too late! Under this point of view, the driver is supported and helped in taking the most appropriate action, with the system able to provide the right information, on the right channels, in the right time, tailored for the specific user.

At the moment, "traditional systems" allow to satisfy a subset of these requirements and user's needs and moreover in static way: a snapshot of the external scenario and the assessment of this. A further step consist in being aware of its own limitations, so that the system can inform the driver on the level of support it is able to provide in a given situation and specific condition.

Applying the aforementioned concept of AC, the car should be reactive, namely it feels and is able to adapt itself to environment; in other words, it becomes pro-active, able to perceive the surrounding external scenario and to be always active and present. These types of systems should be completely adaptive and dynamic, since they have to take into account the following aspects:

- ❖ change of (external) operative conditions
- ❖ features and characteristics of the users
- ❖ variation of the internal scenario

The car has therefore to adopt reflexes in order to support the drivers when needed, with the scope to design a system which responds without substituting the user's intelligence; in fact, in the last years, under the influence of "artificial intelligence", we have been looking for an "intelligent" car (but intelligence is something you never catch – see the name AICC ⇒ Adaptive Intelligent Cruise Control...). Maybe now is time to wish a "**responsive car**", able to really co-operate with the driver in dangerous situations; being aware of the *surrounding environment* (safety belt all-around-vehicle approach), of the *driver's needs*, and – above all – able to adopt and react to external modifications of the environment, the new systems **adopt "reflexes"** in order to help in avoiding an accident (supporting the users when they can do it and informing drivers when not ) or at least to reduce the damages and consequences of it.

### **31. TAYLOR, ROBERT: POSITION STATEMENT**

Since the 1980s, UK Ministry of Defence, and other government defence agencies, have made significant research investment in the development and demonstration of decision support systems (DSS) for a range of military applications using artificial intelligence (AI) techniques, in particular knowledge-based systems (KBS). These include intelligent KBS/DSS for navy surface ship command and control (C2); for naval air anti-surface, anti-sub surface, maritime airborne early warning (AEW), surveillance and control operations; “pilot assistant” DSS for transport, rotor-craft and fast-jet tactical operations; and most recently, “operator assistant” DSS for supporting supervisory control of multiple uninhabited air vehicles (UAVs). The methodologies needed for knowledge acquisition, modelling, and design implementations of intelligent DSS are complex and expensive to perform, but reasonably well understood. Also, the potential operational benefits of automated information processing techniques (data/information fusion) and intelligent DSS operator aids seem reasonably well appreciated, in particular as mitigation for increasing pressure on, and competition for, scarce technical manpower skills. However, demonstrating life cycle cost/effectiveness remains a concern for investment appraisal analysis and procurement strategy. Currently, the main issue seems to be how to progress the technology readiness of DSS further and effectively to higher levels of readiness, sufficiently to provide transitioning from demonstration prototypes into exploitation in acquisition of fully operational systems. Work is needed on the development of practical systems engineering procedures and human systems integration (HSI) methods for delivering cost/effective intelligent DSS. In particular, the development of robust, discriminating and reliable metrics are needed – both measures of performance (MOP) and measures of effectiveness (MOE) - for the specification, development, test, evaluation, validation and certification of intelligent DSS. In addition, and perhaps surprisingly given the maturity of human factors engineering and human computer interface (HCI) design, there seems to be a lack of practical experience and understanding of system and user requirements for effective and intuitive user interfaces and interactions with intelligent DSS. With the current heavy emphasis on developing UAV operations, and the integration of DSS with autonomous decision making technologies, the implications for decision making autonomy, authority and human-in-the-loop (HITL) supervisory control, are areas of increasing interest and concern. Specifically, there seems to be poor understanding of the user requirements for HCI with intelligent DSS, where interfaces and interactions are needed to preserve and support the HITL decision making and critical appraisal skills during real-time dynamic adaptive systems control with safety critical systems.

### **32. WATSON, MARCUS: CONSTRAINT BASED DECISION-MODELLING FOR MILITARY COMMANDER DECISION SUPPORT TOOLS**

Defence forces around the world have used computer generated forces to simulate battles in operation analysis studies for military exercises. Computer based wargame simulations are used to model the behaviours of constructive entities (i.e. simulations for infantry, tanks, truck, aircraft of any type, etc.). Subsequent behaviours such as communication between entities, group assignments, individual roles and responsibilities in a platoon, company and battalion are also modelled. In most computer based wargames, there is a high reliance on humans to act as command decision-makers. The reliance on humans to conduct command decision-making is costly in terms of the number of participants required to conduct each wargame. Many attempts have been made to produce intelligent agents to replace human actors in wargames but without much success [1].

Heuristics reasoning algorithms based on interviews with commanders have failed when uncertainties must be included in the simulated human decision-making processes. Attempts to use computer learning have worked for the situations in which the agents are trained on but fail when a new situation arises because there is insufficient data for the systems to learn the complexity of factors influencing decision-making. Rule-based processes that rely on normative or descriptive models of the domain also fail the first time they encounter a new situation. To deal with unanticipated situations we have develop a formative model of commander decision-making using cognitive work analysis (CWA).

CWA has been applied in various domains including power plant control, aviation, medicine and the military to help analysts develop an in-depth understanding of complex socio-technical systems [2] [3]. In the military environment we have used CWA to identify the physical and organisational constraints limiting commander's decision-making. The decision-model has be used by the Defence Science and Technology Organisation to produce COMATS intelligent agents for wargames that are better able to deal with unanticipated events than previously developed intelligent agents [1] [4] [5]. The COMATS intelligent agents can generate a series of plans by considering the available courses of action; taking into account time constraints, available recourse, the enemy, the environment as well as the agent's commander's goal. The decision model allows the agents to evaluate plans according to military principles and their ability to achieve the task. Selection of a course of action is based upon identifying which plans can complete the task and best leave the agent in a position to carry out future tasks.

One issue for constraint based commander decision-models is whether the constraints of a computer-based wargame actually reflect the real constraints for commanders in operational environments. If the constraints can be identified in real environments then decision-support tools that reveal constraints may reduce the time taken for commanders to make decisions and may lead to better choices in the course of action they pursue. The concept of applying CWA to identify constraints limiting a commander's decision-making is now being transferred from simulated environments to real military commands. We are in the process of identifying the constraints for a maritime decision support tool that will display physical and organisational constraints limiting a commander's successful course of action.

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### **33. WOLTJER, ROGIER: SUPPORTING CONTROL THROUGH CONSTRAINT RECOGNITION**

In this paper we discuss the utility of the concept of constraint in the design of support systems for process control. The paper draws upon concepts from the book on the 1985 NATO ASI meeting on Intelligent Decision Support in Process Environments and adds current Cognitive Systems Engineering (CSE) concepts. Our focus is the roles of Joint Cognitive Systems and the recognition of constraints in process control.

First, the stance of Cognitive Systems Engineering (CSE) is discussed. Second, the inadequacy of the classical option generation and evaluation paradigm of decision support is contrasted to the CSE approach of striving for joint cognitive systems to retain control. Third, the important concepts of time and goals are briefly discussed. Fourth, the theory of supporting control through the recognition of constraints is outlined. Last, the concepts discussed are applied in three domains where the application of CSE is particularly appropriate: command and control, driving, and aviation safety.

#### **33.1 Purpose and control**

We take the stance of Cognitive Systems Engineering (CSE). A cognitive system (Hollnagel & Woods, 2005) is a system that can control its behavior on the basis of experience towards its goals. The term Joint Cognitive System (JCS) means here that control is accomplished by an ensemble of cognitive systems and (physical and social) artifacts that exhibit goal-directed behavior. In the areas of interest to CSE, typically one or several persons (controllers) and one or several support systems are part of a JCS, which in a complex environment is jointly engaged in some sort of process control.

To control a process is to steer the behavior of the process. Thus, when considering the design of support systems for process control, it is useful to consider the theory of cybernetics, meaning steermanship, the science of control. According to cybernetics pioneers Rosenblueth, Wiener, and Bigelow (1943), purposeful behavior is behavior that can be interpreted as goal-directed, on the basis of feedback and prediction. Hollnagel & Woods (2005) also state that being in control means knowing what has happened and what will happen.

#### **33.2 Support through intelligent automated option generation and evaluation**

The term ‘decision making’ refers to a mental process that precedes the execution of action. The decision making process is widely described as including the sub-processes of generation of options, the evaluation of the desirability of these options, and the selection of an (optimal) option for execution (see e.g. Doherty, 1993). Consequently, many authors have stated the role of decision support systems as to take over one or several of these processes (cf. Fischhoff, 1986; Parasuraman, Sheridan, & Wickens, 2000).

However, letting automation do these tasks often introduces more problems than that it helps the controller (e.g. Bainbridge, 1983; Dekker & Woods, 1999, 2002). Hollnagel & Woods (2005) note that especially the intelligent evaluation of alternatives, and choice of most appropriate action given performance conditions (constraints), is difficult for machines, because they are bad at finding appropriate criteria for evaluation. The complexity of goals and existence of multiple ways to achieve these goals, treated later

in this text, makes evaluation even more difficult and dependent on the specific context. These reflections result in the CSE view that states: "From the joint cognitive system perspective, the intelligence in decision support lies not in the machine itself (the tool), but in the tool builder and in the tool user." (Woods, 1986, p. 173).

### 33.2.1 *Supporting JCS to retain control*

The CSE view on intelligent decision support for process control is highly influenced by the principle that a JCS controls its behavior to achieve its goals. Any analysis of the performance of JCS should rely on directly observable phenomena. The unit of analysis is therefore not decision but action. Rather than supporting decision making, CSE aims to support actions directed at retaining control (see also the position statement of Björn Johansson). In this view interaction between the various parts of the JCS has to be designed to enable the JCS to cope with complexity and to handle disturbances on the way to retaining control. This view recognizes that process control environments are often fundamentally complex and that oversimplifying the interaction would likely reduce the JCS' ability to retain control (Hollnagel & Woods, 2005).

## 33.3 Time

Time is a constraint on any decision making process (e.g., Volta, 1986). In process control, time constrains both the evaluation of feedback and the prediction of future behavior. Support for control must take the unfolding of events over time explicitly into account for the JCS to accurately interpret the feedback obtained, to make sense of what is going on, and to predict what is going to happen in the future.

Another important aspect is that process control often involves parallel processes with different time scales. The Extended Control Model (ECOM) of cognition also recognizes time in that the model has multiple parallel layers with different time scales, on a continuum from compensatory to anticipatory control. It describes the control layers of tracking, regulating, monitoring, and targeting (see Hollnagel & Woods, 2005).

## 33.4 Goal fulfillment

A goal is often described as a final condition in which the behaving system reaches a state where given criteria have been met. Many definitions of control and decision making consider only one goal. This oversimplification neglects some important characteristics of goals often encountered in process control in complex environments, which should be taken into account in the design of artifacts that are supposed to support goal-directed behavior.

(1) As task analysis methods such as Goals-Means Task Analysis (GMTA, Hollnagel, 1993) show, the fulfillment of the top goal in complex tasks involves the achievement of numerous subgoals. (GMTA reveals the goal of the task, the specific subtasks that need to be executed to fulfill the goal, and the preconditions that need to be met to accomplish these specific subtasks. The latter form the new subgoals in a recursive analysis of goals, tasks, and preconditions.)

(2) The characteristic of multiviability (expressing that multiple ways exist to achieve a goal, see Hollnagel, 1986) seems to apply to a wide range of tasks in complex environments. In process control environments with many variables that can be

controlled, or when variables can be manipulated over a wide range of values, the various ways of achieving high-level abstract goals seem pragmatically innumerable.

(3) Research on dynamic decision making (Brehmer, 1992) illustrates the characteristic of polytely: that often not one but many, possibly conflicting, goals have to be satisfied to some extent. There may be priorities given for these goals, that make it easier for people to choose appropriate action, but trade-offs in goal fulfillment can be difficult.

(4) Goals are sometimes not clearly stated. Especially when one of the goals is to get as far away from a given criterion as possible (for example when trying to make profit), it may be true that the goal (maximize profit) is explicitly stated but it can hardly be described as having a well-defined criterion of fulfillment. So not only deviation-counteracting, but also deviation-amplifying aspects of mutual causal processes (Maruyama, 1968) have to be considered.

To summarize the discussion so far, our view is that the classical model of decision support systems – generating, evaluating, and selecting alternatives for action has severe drawbacks. In the view of CSE, if support is to be provided, Joint Cognitive Systems should be supported to retain control. The goals of the JCS, and opportunities for feedback and prediction are hereby essential. Support systems for process control should take into account that the process' behavior over time is essential, and that the goal structure often is complex in process environments.

### **33.5 Supporting control through constraint recognition**

In the many tasks where the option generation and evaluation paradigm of intelligent decision support systems seems inappropriate, other ways of supporting the JCS to retain control may be found. For the domain of air traffic control, Dekker & Woods (1999) mention an alternative form of supporting controllers: "In one situation, controllers suggested that telling aircraft in general where *not* to go was an easier (and sufficient) intervention than telling each individual where to go" (p. 94). Similarly, the approach to decision support that we are currently investigating is to support control through recognition of constraints.

#### **33.5.1 Constraint**

Following Reitman (1964) we define constraint as a limit on goal-directed behavior, or an opportunity for goal-directed behavior, or both. In CSE constraints are recognized to shape action (Hollnagel & Woods, 2005). Similarly, the related disciplines of cybernetics and systems theory consider the concept of constraint to be of major importance, because constraints facilitate control.

In cybernetics, constraints are recognized to play a significant role in process control. One of the most fundamental principles of control and regulation in cybernetics is the Law of Requisite Variety (Ashby, 1956). This law states that a controller of a process needs to have at least as much variety (behavioral diversity) as the controlled process. Constraints in cybernetics are described as limits on variety. Constraints can occur on both the variety of the process to be controlled and the variety of the controller. This means that if a specific constraint limits the variety of a process, less variety is required of the controller. If a specific constraint limits the variety of the controller, less variety of the process can be met when trying to exercise control. Regarding the prediction of future behavior, Ashby notes that if a system is predictable, this implies that there are

constraints that the system adheres to. Knowing about constraints on variety makes it possible to infer what the system will do next.

Systems theory (e.g. Checkland, 1981; Leveson, 2004) treats systems as hierarchically organized components. For control to emerge, components need to interact. Loss of control results from a lack of appropriate constraints on component interactions. A system design must continually enforce the appropriate constraints to ensure control. Interactions between hierarchically organized components form adaptive control loops at various control levels. Information to enforce constraints is communicated downward in the hierarchy of components; feedback to ensure that constraints have effectively been enforced is communicated upward.

Thus, constraints have both the role of limiting behavior and facilitating control. It is important to know about constraints to be able to exercise control and anticipate when control may be lost.

### 33.5.2 *Visualizing constraints*

Woods (1986) emphasizes the importance of spatial representations when providing support to controllers. Visualizing constraints is the support strategy that is proposed here. Ecological Interface Design and Representation Design (Vicente & Rasmussen, 1992; Woods, 1995) offer design guidelines concerned with constraint: Decision support systems should facilitate discovery of constraints, represent constraints in a way that makes the possibilities for action and resolution evident, and highlight the time-dependency of constraints.

One way to do this is by means of state spaces. State spaces are often used in the discipline called the dynamical approach to cognition (Port & Van Gelder, 1995). Dynamics is concerned with the behavior of systems over time. State spaces illustrate how the state of a system changes over time. State spaces can be created if the (part of) system behavior to be illustrated can be described by a clearly defined set of variables that change over time. A state is associated with a choice of value for each of these variables. The collection of all possible or relevant states is called the state space. The behavior of dynamical systems over time can thus be visualized using state spaces.

### 33.5.3 *Applications in our research*

We have conducted research to illustrate the utility of the concept of constraint in various kinds of process control. Three domains of interest will be briefly discussed here. Note that the process control tasks in these domains differ widely in organizational complexity and time scales involved, enabling a broad discussion of the utility of the constraint concept.

### 33.5.4 *Command and control*

We are currently investigating a method of performance analysis and decision support through the recognition of constraints in distributed collaborative command and control (Woltjer & Smith, 2005). In the settings of interest, the controllers (or decision makers) that form the JCS are typically organized in a flat network-based structure. They are mutually interdependent because they manage resources that others in the JCS need to jointly accomplish the overall goals. Because of this mutual interdependency, actions of one controller have implications for the other members of the JCS. The actions of one

controller form constraints on the actions of others. In this way, constraints are said to propagate, to make new constraints or to change existing constraints. The characteristics of polytely, multiviability, and existence of many subgoals apply to these settings. Our current experimental platform is the C3Fire microworld (Granlund, 2003) where the participants engage in the task of fighting forest-fires. The analysis of performance in terms of state spaces and constraints is currently underway.

### 33.5.5 *Automobile driving*

Automobile driving can be seen as a process control task. The JCS of driver, passengers, and automobile, tries to achieve the goals of safely but efficiently steering itself to a destination (Hollnagel, Nåbo, & Lau, 2003). Many constraints exist, such as the locations and width of roads, state of the road surface, mechanical properties of the engine, brakes, etc. Goals exist on many time scales: the JCS needs to maintain a particular lateral distance from road sides, to navigate a curve or a set of curves in a certain way, and to reach a final destination, to mention a few. Many technical systems under development in industry and academia are meant to provide information, issue warnings, take control, and/or support driving in some other way (for examples see Lu, Wevers, & Van der Heijden, 2005) in the name of safety, efficiency, and comfort.

Some descriptions and investigations of constraint in driving can be found in literature, of which two will be mentioned here. In their theoretical field analysis of automobile driving, Gibson & Crooks (1938) describe the field of safe travel, a field that can be seen as a field delimited by the constraints that the environment puts on the safe movement of the automobile. A more recent example is the study by Flach, Smith, Stanard, & Dittman (2004) that demonstrates how braking performance represented in an optical state space reflects how constraints are handled. Their state space represents (1) distance to relevant textures (for example the car driving in front of you) through the variable of the optical angle associated with the texture, and (2) closure rate to that texture through the variable of angular expansion rate. Performance of the JCS can thus be illustrated and understood better with the help of representing constraints in state spaces.

In an experiment of driving in a virtual world, we have investigated the effect of the constraint of road (path) width on driver performance (Zhai, Accot, & Woltjer, 2004). While holding all other constraints constant, the manipulated environmental constraint of road width was found to systematically affect driving performance in a task where participants were asked to drive as fast as safely possible on straight and circular road segments. Because many constraints that occur in natural settings of driving were not present during the experiment, this study tells more about movement that is similar to driving in a simple virtual world, than about driving in natural settings, but the systematic analysis of the effects of individual constraints is useful in understanding tasks such as driving.

### 33.5.6 *Aviation safety*

The JCS of managers of airlines, maintenance personnel, pilots, governmental organizations concerned with safe flight, air traffic controllers, etc. is jointly concerned with safe flight, but also with efficiency of all processes that are involved in the air transportation system (Smith, 2001). Unfortunately, the effects of competing goals of safety and efficiency contribute to accidents, in which control of the processes that

constitute safe flight is lost (see, for example, the loss of control of Alaska Airlines flight 261, discussed in Dekker, 2004). In Leveson's (2004) systemic accident model, which has its basis in systems theory, an accident results from inadequate enforcement of constraints, as was described earlier. An other new systemic accident model is presented by Hollnagel (2004), in which functional resonance of impaired or missing barriers, latent conditions, technological failures, and human performance variability is of major concern. Barriers are hindrances that may either prevent an unwanted event to take place, or protect against the consequences of an unwanted event (*ibidem*). Barriers form constraints on processes, and thereby enable control. Constraints seem to play a critical role in controlling safety-critical processes. Knowledge of constraints, violations of constraints, and the resulting propagation and effects of constraints are also among our current research interests. Possibly the explicit representation of the handling of constraints over time could aid controllers and managers in the complex world of aviation to recognize when safety goals are endangered.

### 33.6 Conclusion

The literature on automation illustrates that the classical model of decision support systems – generating, evaluating, and selecting alternatives for action has severe drawbacks. In the view of CSE, if support is to be provided, Joint Cognitive Systems should be supported to retain control. Constraints are recognized as essential to enable control. To offer support, artifacts could be designed to be a part of the Joint Cognitive System that makes controllers aware of the existing constraints on their actions. The current direction of our research is to analyze joint system behavior relative to constraints and to investigate the possibilities for the visualization of constraints as support for process control tasks.

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### **34. WREATHALL, JOHN (CO-AUTHORED WITH MERRITT, ASHLEIGH): THE MESSAGE IS THE MEDIUM**

When does the style of presentation of safety data matter to management? Work on leading indicators of human and organizational performance has led to the development of measures to help management know where they are in 'safety space' (e.g., Rasmussen's 3-dimensional graph). However, the ways in which this information is presented plays a critical role in management being able to understand and take action on it. Too often management is presented with the worst kinds of data display: time trend charts from Microsoft Excel. While this may be an extremely low-tech issue for a high-phalutin' conference like this, it is perhaps a diverse application of "intelligent decision support systems". Like other support system designs, it is of course important to consider what are the decisions, and on what basis are they made, when evaluating such support systems. Our work has gone in the direction of providing very specific answers to very specific questions; questions that even the managers were often unaware that they were asking.

Starting with the view that many types of indicators (especially org. cultural/behavior ones) can parallel the traditional psychological questionnaire/survey paradigm, consider the following:

- First designed to measure cognitive ability (IQ tests) and personality – both complex intra-psychic constructs that the individual cannot clearly articulate without help
- Also attitudinal tests that try to “trick” respondents into revealing their true but negative attitudes, e.g., racism, anti-social behavior
- There is some all-knowing being, the analyst, who will translate the person’s responses into truth (academic conceit?)
- Statistical reliability is usually achieved through multiple items per construct. Although tedious for the respondents, this was often not a problem as subjects were either students (getting class credit for their time), or people being tested in the clinical environment
- Each individual should complete the questionnaire without knowing what others have written – this must be a hangover from academics (“no cheating”)
- It is often the case that you have to wait a long time after you complete the survey to learn anything about the results – this seems to add to the mystique of the process.

Problems with this paradigm when applied to culture and other types of organizational measures:

- The methodology for group surveys is still premised on finding the one truth (often arrived at by averaging - how silly is that?) but OC is about shared meaning and perceptions - there isn't one precise truth we're seeking.
- You're not delving into the psychic or trying to trick the respondent with indirect questions. There is no trick – whatever a person thinks about their org is their

truth. This ‘truth’ can be enhanced however with increased knowledge of the org. A person who knows more about what is going on - who is not ignorant about org processes - may have a more educated/aware/informed perception. The way to get better quality answers is not to trick the respondent, or to ask them several questions on the same theme, but to educate them about the organization and its practices. (to sharpen their perception, bring things into focus, address rumors, announce changes)

- A learning organization or learning culture is premised on all members in the collective sharing their knowledge and applying their learning. We want to tap into this sense of collective sharing and learning
- Let’s remove a lot of the mystique and sense of “higher-up” power in traditional surveys, and democratize the process for the org members. This will help remove suspicions about Senior Leaders “messing with the data” and make the whole thing more transparent. The more transparent, the more opportunity for learning on all fronts

What can be done then? One idea we have been working on (especially Ashleigh) is as follows. Ashleigh got this idea initially from Amazon (where you get to read other people’s reviews and rate them as useful or not).

It is standard to ask people for critiques or suggestions for improvement. This obviously needs to be text-based so as to not constrain them. However this list quickly gets unwieldy, and there is no way to truly discern the good suggestions from the chaff. This task often falls to one or two individuals or committee – not much chance for org-wide learning here. To change this

Step 1: Have categories as part of a pull-down menu for the suggestions. If they want to comment on procedures, they write in that box; they should be able to write as many suggestions as they want in as many or as few categories as they want, including multiple suggestions for the same category. The person gets to decide if they want their suggestions to be anonymous. (I bet if they think it’s good, they’ll put their name to it)

Step 2: These suggestions should be available to everyone. A person should be able to write their suggestions and then go in and rate other people’s suggestions. A person might be curious what other people wrote in the Procedures category, so they pull down all suggestion so far, and rate them (rating scale using stars, something like: this is a great idea, I think it would make a big difference... good idea, but not a priority .... This idea won’t work). The person can both rate the suggestion, and also provide a comment if they wish (a sub-comment if you will). Just like Amazon, you could also have a counter of how many people read and rate the suggestion

Step 3: the powers that be (from supervisors to dept. heads to cross-disciplines and senior mgmt) can read these suggestions, and pay attention to the collective wisdom that will create a natural prioritization and selection process. It would be a nice feature if you could call up the suggestions not only by category but also endorsement (e.g., all suggestions with a rating of 3 stars or higher).

It is also necessary to time stamp the suggestions, so that you can go in and ask for the suggestions added since the last time you looked. This is a living document, moving

forward, so time stamping will help keep a track of which suggestions are attracting comments, and which suggestions do not.

Step 4: When an action is taken in response to a suggestion, there is a big thumbs-up symbol or something equally flashy and positive to indicate action was taken on the suggestion. Clicking on the symbol could link to the action details (similar to a corrective actions database).

Step 5: there can be a periodic cleaning out of the suggestions, e.g., Could create a rule – no comments on a suggestion for 3 months, the suggestion goes to a secondary database. drop all suggestions with 1 or fewer stars rated by X or more people to a secondary database.

Step 6: Ask people to also rate and comment on the actions taken. While this may initially seem like overkill, I think it would help promote collective awareness and close the loop (or extend it if someone can see a new idea to follow from the action). What we hear from many workers is that they write up an event or make a suggestion and never find out if anything happened. This way, they can go to their suggestion, see if it got a thumbs-up, see the action taken, and again in the spirit of shared organizational wisdom, they and others can comment on its effectiveness. It's a great way to publicize the actions taken, and it also promotes the idea that the organization is always learning. Maybe the action taken wasn't effective, as rated by the workers, which leads to new ways of doing things. Very transparent actions.

A second approach to the use of org data is to use it to construct stories rather than trends and other crap plots. Stories are what get management attention. Therefore when getting the cultural data inputs, always ask for instances and examples of what is being rated. Thus, when priorities are being worked out, the actual instances feed the decision-makers' process (what a concept!!). We have sat through endless meetings with management as they are faced with the inevitable pretty plots from Excel. The honest managers say that this tells them nothing, and they do not want it. It is only noise. What they need are the underlying stories, prioritized according to some sort scheme. Thus an indicator may be a high priority because more than 50% of the staff have rated it as an important or quite important concern. Indicators tend to be 'high level,' like "communications", but what is the real problem with communications? The stories are the details of the problem, without which managers are usually shooting in the dark.

### **35. YOON, WAN CHUL: KNOWLEDGE STRUCTURES FOR INTELLIGENT DECISION AIDS**

#### **35.1 Intelligent Decision Support and Knowledge Works**

The need of intelligent decision aiding is almost always coupled with human knowledge works. As human works becomes more knowledge-based or knowledge-bound, knowledge becomes the key determining factor in designing intelligent decision support systems (IDSS). The important characteristics of human knowledge in works that are relevant to the roles and design principles of IDSS are: (1) knowledge has a life cycle (2) knowledge is organised and highly relational (3) knowledge is learned, better in intuitive ways, and its use can be practiced (4) there is a personal or task-specific diversity in human knowledge and its use. The design and evaluation of an IDSS should be based on these characteristics of human knowledge and related human behavior.

#### **35.2 Knowledge and the Spectrum of Topics in IDSS**

The spectrum of intelligent decision support can usefully be derived from the life cycle of knowledge in human works, which comprises of acquisition, pre-processing, use in decision making, storage and maintenance. Corresponding elements of IDSS for the stages are automated or interactive knowledge acquisition [6], intelligent information processing to match the human strategies [5, 7], intelligent interfaces with cognitively designed information representation [2, 3] or interactive optimisation [1, 4], and knowledge management systems [4], respectively. In each of these elements of IDSS, the other three characteristics mentioned in the above can be considered to provide the directions for advancing IDSS application as well as research topics.

#### **35.3 The Cases: Representing Knowledge Structures to Aid**

This statement is focused on the importance of considering the human knowledge structures for designing effective IDSS's. The human work knowledge is highly structured and organised with relations, of which types include abstraction, decomposition, causalities, and so on. The knowledge structure and relations provide the keys to the design of effective decision aid.

In a study to examine the supporting effectiveness of ecological interface design [2], we found the system state information helps the operator better when it is represented at multiple, related levels of abstraction. Although the multi-level information was displayed without other aiding features such as graphics, the operators seemed to be able to get cues and explanations from the displays as needed. The system helped by presenting the useful relations in knowledge, not by replacing the human reasoning.

Another experimental study evaluated a design decision support for user interface designers [4]. The system was similar with case-based systems but unique in its presentation of prior design solutions at multiple levels of abstraction. Industrial designers participated in the experiments and the results showed the effectiveness of the designed representation which provided vertically related solutions along the abstraction hierarchy. As in the first mentioned study, this implies that the decision support system should intuitively present the structure of information when the structure is to be explored by human strategies for decision making. Also, both studies indicated the importance of supporting the use of abstraction relations.

The knowledge structure may be very different depending on the tasks even when describing a same system. An example is the distinct descriptions of a same piece of UI (user interface) software between the UI designers and software engineers. UI designers prefer to use a flow diagram of user-device interaction for given tasks to examine the convenience and consistency of the interacting methods. The software programmers need to have a state transition diagram that describes how the elementary modules need to be formed and controlled. Since the two expert teams are working on the design of the same software, the gap between the views and models that they use is apt to hamper the communication and hence the quality of implementation. To help such cases, a design decision support system was constructed [5]. It converted between the two types of models to help designers to verify both aspects of the interface. This system, being more active than the first two, was shown helpful in an evaluation where industrial designers participated.

### 35.4 Conclusions

Where intelligence needs to be aided, there exists task complexity. Task complexity should almost always be dealt by heavily organized knowledge. The common conclusions from the three studies are that the information should be represented in an intuitive way, and the intuitiveness is determined by the way in which the human utilises internal organisations in the relevant knowledge. At times, the support system should manipulate or even create the relations required to (re)organise the knowledge into a fashion that is intuitive for a particular task. Since there are other structural aspects of knowledge, such as schemata, scripts, causalities and correlations that may be utilized by human decision makers, the same principle may be extended to wide variety of supporting approaches. Analyzing the knowledge structures and their use should become the core in any disciplined design processes of building IDSS.

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## **36. APPENDIX: INTRODUCTION TO THE PROCEEDINGS FROM THE 1985 MEETING**

### **Introduction**

The increasing complexity of technological systems has shifted the demands on human performance from a mechanical/physical level to a cognitive level. The role of the human in complex systems is to act as a supervisor of automated or semi automated resources with goal setting, problem solving, and decision making as the primary tasks. While the negative consequences of possible malfunctioning have grown, the tolerances for performance variability have been reduced and the demands to accurate and safe performance increased, thereby leaving the human operator in a very difficult position. At the same time, advances in computer science (e.g. automated decision makers, object oriented programming, and expert systems) have provided new possibilities to support human performance that challenge established man-machine system design principles.

Decision-making has emerged as the focal point for the often conflicting demands to human action. To ease the operator's task one must reduce these demands by incorporating basic intelligence functions in the man-machine interface. But it is essential that an intelligent interface supports the operator's decision making rather than replaces parts of it, i.e. that it is a tool rather than a prosthesis. The former may improve the task, while the latter will surely aggravate it. The logic behind decision-making has been considerably extended in recent years, for instance by fuzzy-set theory and possibility theory. A clear distinction has also emerged between domain specific knowledge and decision-making strategies. Decision making is no longer regarded as simply the strict following of a single set of rules or a strategy, but must also include the selection of the appropriate rules and the possible switch between them as the decision evolves, i.e. meta-level decisions.

The aim of this ASI was to identify the knowns and unknowns of intelligent systems that can support human decision-making in process environments. The focus was the functional rather than the analytical aspects of such systems. The emphasis on and the development of systems that perform cognitive tasks require a corresponding shift in the multiple disciplines that support effective man-machine systems. It requires contributions from decision theory, theoretical and applied; from philosophy and logic; from process control theory and information science; from cognitive psychology and the study of human performance and human error; and from artificial intelligence and computer science. This was achieved by describing (1) the foundation provided by decision theory, (2) the problems of decision making in process environments, (3) the cognitive aspects of decision making, and (4) the possibilities of artificial intelligence and advanced computer applications. The ASI aimed to synthesise and integrate developments in all four areas.

As mentioned in the preface, this ASI joined a series of other meetings that all had dealt with problems of man-machine systems. The five major previous meetings were:

1976	Monitoring Behaviour and Supervisory Performance	Berchtesgaden, West Germany
1977	Theory and Measurement of Mental Load	Mati, Greece
1979	Changes In Nature and Quality of Working Life	Thessaloniki, Greece
1981	Human Detection and Diagnosis of System Failures	Roskilde, Denmark
1983	Human Error	Bellagio, Italy

The present ASI used the interdisciplinary cooperation and knowledge foundation established in the previous conferences to address the problems of cognitive man-machine systems. During the two weeks specialists from the above-mentioned fields worked together to advance the synthesis of knowledge needed for the development and evaluation of such joint cognitive systems, present the current unsolved problems, and point to possible solutions. The outcome is documented in this book.

Whereas most readers of this book probably will have a good understanding of what decision making and decision support systems are, it may be useful to describe briefly what is meant by process environments and how decision making In process environments differs from other types of decision making.

Process environments are first of all characterised by having short time constants. The decision maker must constantly pay attention to the process because the state of it changes dynamically; if he fails to do so he will lose control. If time was not that critical it would be possible to leave the process and look for information in other places, consult available experts and knowledge bases, etc. To use an example from medicine, if time is not critical one is dealing with a population phenomenon, for example the effects of smoking; if time is critical one is dealing with an individual phenomenon, for example toxification. If there is no time pressure one can always refer to data from the population and neglect the process without endangering it.

Formal decision theories do generally not contain any element of time (cf. the paper by Giuseppe Volta), hence fail to recognise an essential attribute of process environments. They are therefore not directly applicable but require further development and modification.

Another characteristic of process environments is the uncertainty about data, i.e. one is uncertain about what the next datum may be. There is less than complete predictability of what evidence will appear, both on the level of individual process parameters and on the level of the process as a whole. The uncertainty does not only arise from the imperfection or breakdown of single components as in normal reliability analysis or Probabilistic Risk Analysis. Far more important is the uncertainty of the evidence that comes from the dynamics and complexity of the process as such. This lack of certainty is in conflict with some of the main assumptions of both normative and descriptive decision theory and naturally makes decisions more difficult (cf. the comments by George Apostolakis).

Process environments are further characterised by being dynamic, by having multiple and possibly conflicting goals, and by having incomplete information. The latter may lead to tradeoffs between the speed and quality of the decision. Decision making in process environments normally means multiple decisions based on partial information, with little chance to consider all the alternatives or to make revisions. It is thus very different from the orderly world that is assumed by conventional decision theories - and provided by most of the experiments carried out in the behavioural sciences.

The presentations and discussions at the ASI, as well as the papers in this book, are organised in four sections corresponding to the four main aspects of Intelligent Decision Support Systems. These are decision theory, cognitive engineering, systems engineering, and artificial intelligence. The development and application of Intelligent Decision Support systems must be based on a combination of these four aspects, as none of them is sufficient on its own. Each of them refers again to other scientific disciplines some of which, like cybernetics, are related to several aspects of Intelligent Decision Support. The presentations and discussions at this ASI clearly showed the insufficiency of anyone of these aspects to account completely for the functioning of Intelligent Decision Support Systems, but also demonstrated how interdisciplinary cooperation can bring about new ideas and solutions.

Decision theory, whether normative or descriptive, is a natural starting point for this book. It provides a basic understanding of the theoretical and practical issues and of the currently unresolved problems. Cognitive engineering gives the view of a recent combination of a number of disciplines that all focus on the cognitive aspects of system functioning, and in particular addresses the relation between knowledge and decision-making. This view is closely related to the current developments in systems engineering which, together with decision theory, represent the more established views. The section on systems engineering summarises and identifies some of the shortcomings of a traditional engineering approach, and points to ways in which they can be solved. Finally, the section on artificial intelligence provides the experience from trying to incorporate intelligent capabilities in artificial systems. Artificial intelligence has produced a fascinating repertoire of ideas and tools, which can be applied in developing Intelligent Decision Support systems, and the influence on cognitive engineering and systems engineering is obvious.

We believe that these four aspects are both necessary and sufficient to give a comprehensive description of Intelligent Decision Support systems, to point out the major problems, and indicate how the solutions can be achieved. It is also our strong belief that solutions can only be achieved by a combination of two or more of these disciplines. The insufficiency of an approach to Intelligent Decision Support systems based purely on either of them is demonstrated both in the papers and in the summarised panel discussion. Decision theory and systems engineering both focus on a description of the problem domain, decision making in process environments. Cognitive engineering and artificial intelligence provide an outline as well as examples of the methodological and functional solutions that can be applied on the problem domain. This ASI was an expression of the clearly recognised need for an interdisciplinary cooperation, and we trust that the book demonstrates the benefits of mixing minds and metaphors as a foundation for further advances into a new and challenging field

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